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Cost Effective Enclosure of Surface Preparation and Coatings in Floating Dry Docks

U.S. DEPARTMENT OF THE NAVY
CARDEROCK DIVISION,
NAVAL SURFACE WARFARE CENTER

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Cost Effective Enclosure of Surface Preparation & Coatings in Floating Dry Docks

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Section 1 SUMMARY

Tensile architecture appears to be the most promising building method for the development of cost effective enclosure of ship repair processes that occur in floating dry docks. Tensile structures are ancient. The earliest recorded home construction project occurred nearly 400,000 years ago[1]. These ancient houses consisted of saplings stuck in the ground around a perimeter, bent towards the middle and laced together to create a frame. Grass, leaves, straw, mud, or animal skins were use as thatching to provide protection from the elements. These early houses incorporated the principles of tensile construction; the strength to resist violent weather with efficient use of readily available material. Tensile structures have only recently been identified as an architectural form. Robert Kronenberg[2] notes, "There is virtually no mention in architectural history of building based on tension systems before 1945, and yet there have been many substantial structures before this that have admirably expressed the design principles that are now the basis for one of the most exciting architectural forms of the twentieth century." Later developments in house construction saw the development of woven fabrics and the houses became portable capable of withstanding severe weather. The development of rope led to the development of wire cables. Early bridges were constructed using tensile principles and modern bridges use the cantenary to span great distances. Tensile construction on land went hand in hand with tensile applications at sea. Kronenberg again, "All these structures undoubtedly used skills and materials acquired from shipbuilding in their construction: rope and canvas, and structural techniques developed for raising large, though relatively lightweight, objects quickly and efficiently." The great sailing ships, ancient and modern, use tensile construction to resist enormous static and live loads to generate power. Kronenberg notes that the Cutty Sark, when constructed in 1869, could generate 2,259 horsepower with her 9,997 square meters of sail.

Since 1945, when architects finally recognized tensile construction as a building form, tensile design principles have created numerous large and beautiful structures enclosing vast sports stadium airports and even an indoor beach in Japan. Most tensile structures today are used in large public venue buildings where aesthetics are important. Tensile structures used less in industrial applications. Admittedly pre-engineered or modular, fabric covered buildings are used to create very cost effective structures, but these building are more akin to conventional buildings than are true tensile structures. Containment systems for general surface preparation and painting applications are beginning to use some elements of tensile design but do not yet fully use tension to its greatest affect. Perhaps the low cost of the ubiquitous "blue tarp" prevents true tensile enclosure systems from being developed.

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[1] Berger, Horst. Light Structures – Structures of Light. Basel. Birkhauser, 1996.

[2] Kronenberg, Robert, "Tensile Architecture." Architectural Design Profile #17. (1995): 9-15

Like the ancient homebuilders, shipyards now find themselves using lightweight, readily available materials to construct shelter from the elements. The questions for this report are, can current dry dock enclosure practices be improved upon and can tensile structures be adapted to surface preparation and coatings operations in dry docks without negatively impacting other concurrent ship repair processes? This report attempts to answer these questions.

Section 2 INITIAL FINDINGS

Initial work for this project involved a survey of shipyards and enclosure manufacturers conducted to gain general knowledge about floating dry docks in use the U.S. and the types of enclosure that are available as off-the-shelf technology that may be useful for enclosing surface preparation and coatings activities that occur in floating dry docks.

It became apparent that a cost effective enclosure system for floating dry docks that could satisfy the unique constraints imposed on enclosure by the activities that occur on dry docks did not exist. Certainly, pre-engineered and manufactured enclosure systems could physically contain even the largest of floating dry docks. However, when these structures are evaluated for their impacts on the operational aspects of various ship repair processes, it was determined that a cost effective enclosure system for floating dry docks had not yet been developed.

Initial review of enclosure literature indicated that tensioned membrane or tensioned fabric structures were the most likely building system that could cost effectively enclose floating dry docks. The principle characteristic of these structures that qualify them as likely candidates for dry dock enclosure is there ability to provide large, clear span enclosure with very little mass. That is, they are very light weight. Upon closer review of pre-engineered tensioned fabric structures, the author identified these structures as belonging to the architectural discipline known as *tensile architecture*. The author determined then, that the characteristics of tensile architecture could ultimately be applied to floating dry docks and the industrial processes that occur in dry docks to achieve cost effect cost effective enclosure. The author then proposed a change in scope for completion of project 3-95-5, which was approved by the SP-3 panel. The revised scope for the project then, involves a study of the emerging technology known as tensile architecture and application of tensile design principles to the problem of enclosing ship repair processes on or in floating dry docks. The Ketchikan Dry Dock #1 is used to describe the various enclosure concepts.

A shortcoming of prefabricated tensioned membrane structures is that they are not readily conformable to the myriad sizes of vessels that represent a particular dry dock's service fleet. Therefore, they must be sized to fit the largest vessel expected to use a particular dry dock. A new generation of fabric enclosure is emerging from the containment of general coatings operations that are configurable to fit closely around the specific work area. These new containments use fabric membranes, but often do not fully employ design principles of true tensile structures. Essentially, they rely on conventional framing system to support the fabric. Therefore, these containments require excessive labor for assembly and disassembly to be cost effective for surface preparation and coating operations in dry docks.

This report will provide the conceptual basis for development of innovative tensile structures that will satisfy the unique enclosure demands of ship repair processes that occur in floating dry docks.

Section 3 DESIGN CONSIDERATIONS

Standard building design requirements will apply to construction of enclosure systems on floating dry docks. However, the unique aspects of building on a buoyant foundation coupled with the intensive industrial process occurring with in the isolated and confined space of a floating dry dock will require special consideration to achieve cost effective dry dock enclosure. Ships are small cities. Major maintenance of a city goes on year round. When ships require major maintenance they are taken out of service, placed in a dry dock, and must be maintained and repaired in a period of a few weeks. Compounding the complications of ship repair is the confined space in which these repair processes must occur both in the ship and in the dry dock. Further, because dry docks float, they are isolated from land. This isolation and confinement, requires crane access for delivery of equipment and materials. Dry dock availability is limited and ship owners must schedule docking months, maybe years in advance. The ship owner plans for when the vessels are out of service and shipping schedules must be met. Delays in dry dock impact the shipyard as well as any number of ship owners if schedules must be changed. Cost effective enclosure can help shipyards meet production deadlines critical to both vessel owners and shipyard operators.

The design considerations listed below then must be addressed in a manner that will avoid negative impacts to either the floating dry dock or the ship repair processes that occur in floating dry docks.

1. Wind Loads & Sail Area - Exposure Factor D
2. Snow Loads
3. Weight
4. Dry Dock Stability
5. Crane Access
6. Vehicle & Equipment Access
7. Impediments To Positioning Vessel During Docking
8. Degree Of Weather Protection
9. Degree Of Environmental Protection
10. Fire
11. Ventilation
12. Lighting

Each of these design considerations will require special consideration when applied to enclosure in or on floating dry docks. Some of these special considerations are discussed below.

1. **Wind Loads and Sail Area** -In Ketchikan, the Uniform Building Code (UBC) requires structures to be designed to withstand 100-mph winds with an exposure factor D. Exposure factor D is defined, by the UBC, as "*as the most severe exposure in areas with basic wind speeds of 80 mph or greater and has terrain which is flat and unobstructed facing large bodies of water over one mile or more in width relative to any quadrant of the building site.*"

   Where some dry dock owners may be able to make a case for using a less severe exposure factor, most dry dock installations, by virtue being located on the water, should at least be aware of Exposure D.

   Because total forces applied to the dry dock are a function of wind velocity and total surface or sail area, a configurable enclosure system becomes preferable to a non-configurable system. A configurable enclosure system provides the opportunity to closely fit the shape of the enclosure to the shape of the particular vessel being repaired reducing the total sail area presented to the wind. The ability to conform the enclosure around the base of stacks, towers and antennas equates to significant reductions in total sail area when compared to non-configurable enclosures which must be sized to accept stacks and antennas of the largest vessel to be serviced. Configurability complicates enclosure, however, and will affect both acquisition and operational costs.

   Large sail areas and resulting force applied to the dry dock anchoring system is another factor that must be considered. By reducing sail area using configurable enclosure systems, total forces applied to the anchoring system are reduced. Fitting the enclosure system to the vessel shape should not appreciably increase overall wind loads to the dry dock avoiding possibility of having to modify the dry dock anchoring system. Re-founding the dry dock anchoring system would certainly effect the overall cost effectiveness of a proposed enclosure system.

   Wind loading also argues for a system that can be rapidly retracted. If the proposed enclosure system can be rapidly retracted, perhaps the overall system can be designed for lower wind speeds than a system that cannot be retracted. Initial acquisition costs could be reduced by not having to construct a system capable of withstanding hurricane force winds.

2. **Snow Load** - Depending on geographical location of the proposed enclosure, snow loading can be a major factor in determining cost of enclosure. In Ketchikan, structures must design for a snow load of 30 pounds per square foot. As this is a significant addition to the dead weight load on the structure, it could have significant impact on costs not to mention potential problems with dry dock stability.

When considering snow loading on tensioned membrane enclosure systems it should be remembered that, many modern membranes have very low coefficients of friction. They are very slippery. The overall shape of the enclosure should be evaluated to reduce its ability to hold snow. Reductions in the snow loading should be considered for these properly designed tensile structures.

3. **Weight** -The weight of a proposed enclosure system must be evaluated for its affects on dry dock stability and lifting capacity. Pre-engineered fabric buildings can weigh from between 1% and 2% of a dry dock's buoyancy.

4. **Dry Dock Stability** -The sum of enclosures weight and the live loads, wind and snow, that are applied to the enclosure must be evaluated at the critical stages of dry dock stability.

5. **Crane Access** - Crane access must be readily available to any location on the vessel or the dry dock.

6. **Vehicle & Equipment Access** - Man lifts, fork lifts, trucks and small cranes will require access to the dry dock.

7. **Impediments To Positioning Vessel During Docking** - The proposed enclosure system must not impede safe ship handling during docking and undocking of vessels. We have established that for operational affordability the enclosure system would probably need to be mounted on the dry dock. How and where the enclosure mounts to the dry dock will be determined to some extent by the methods used for ship handling during docking events.

8. **Degree of Weather Protection** - Local weather patterns will determine importance of this consideration as well as what measures will be taken. For some locations wind attenuation may be the only desired control. Ketchikan, with its high winds and annual precipitation of over150 inches will require greater degree of weather protection than many other locations.

9. **Degree of Environmental Protection** - The two extremes of environmental protection range from totally open conditions to totally enclosed conditions with complete atmospheric control. Cost effective enclosure systems will probably fall somewhere between the extremes, yet have the capability to achieve total containment if required.

10. **Fire Considerations** - Dry dock enclosure must be comply with fire code requirements, however, fabric structures have special characteristics that make particularly useful for dry dock enclosure.

11. **Ventilation** - Enclosure of dry docks should attempt to minimize the volume of enclosed space to minimize costs of HVAC systems. Passive ventilation may be possible with tension systems.

12. **Lighting** - Many architectural fabrics provide some amount of translucency. This characteristic of fabrics should be used to reduce additional lighting requirements.

Section 4 CLASSIFICATION OF ENCLOSURES

When considering wind loads on enclosure configurable, enclosure systems will have certain advantages to non-configurable systems. In developing a classification system for dry dock enclosure concepts then, the first two classes of enclosure are:

1. configurable and
2. non-configurable.

Non-configurable Enclosures:

This class of enclosures consists of a flexible fabric or membrane attached to a structural frame. The fabric is then mechanically stretched over the frames to resist flutter. This class of enclosure systems is characterized by relatively low cost and lightweight. Depending on the membrane selected for the covering, they can have a service life of over twenty years. Because they are pre-engineered, the detailed engineering phase for conventional structures can be eliminated.

These structures are non-configurable because they prefabricated at the factory for a specific application. Field alteration of the basic shape is difficult hence; they are non-configurable for production purposes in dry docks. Some primary concerns for adapting these structures to floating dry docks include:

1. They must be large enough to accommodate the maximum size vessel expected to enter dry dock including, masts, antennas, towers or stacks.
2. Maximum sizing results in a large sail area transmitting large forces to the dry dock. Dry Dock stability and anchoring must be considered.
3. Crane access is limited to fixed opening locations.

Configurable Enclosure Systems:

A relatively new class of configurable fabric enclosure is emerging in response to the containment requirements of the industrial coating industry. An obvious advantage of configurable systems is the ability to conform the enclosure to fit the shape of a specific work area or job. Total sail area can be reduced to approximate the sail area of the vessel in dry dock. The volume of enclosed space is greatly reduced easing ventilation and worker exposure concerns. First costs can be greatly reduced but operational costs will be higher.

The currently available configurable enclosure systems are proving to be cost effective for the industrial coating industry where the contractor must deliver equipment to the structure to be painted. In many of these instances, providing enclosure is acknowledged as a line item cost. Shipyards on the other hand, are stationary so the structure to be painted is delivered to the contractor. Ship owners are not accustomed to seeing enclosure as a line item cost unless removal of hazardous materials is involved. For this reason, the author believes innovations are required for configurable enclosure to become truly cost effective in floating dry docks

Section 5 TENSILE STRUCTURES

In order to develop innovative tensile structures suitable for use on floating dry docks a review of current tensile design principles was conducted. This section will present the basics of tensile design.

Past & Present Use of Tension Fabric Structures

The earliest buildings to utilize flexible structural members appeared nearly 400,000 years ago. These structures were formed by lacing saplings together to form an arch and then covering the resulting flexible frame work with woven straw, reeds, leaves or grass. Surprisingly, these early tension arch frames provide the shape and theory for what has been identified as useful for enclosure of floating dry docks. It is the ability of these early tensile structures to deform under wind and snow loads to increase resistance that makes them useful examples for a modern tensile system that could enclose repair processes in floating dry docks.

Tension fabric structures, membrane structures, tensile structures or tension structures are all names used to describe the architectural form represented by those early flexible stick buildings.

Where the ancient tensile structures relied on simplicity and available materials to provide minimal shelter, the last two decades have seen rapid development of new materials and computer aided design advances allowing construction of huge tensile structures in remarkable configurations. For the most part the new generation of tension structures has been used in sports arenas, performance centers, exhibition halls, and airports. Principally, tensile structures are used large public areas where aesthetic appeal is an important consideration in determining the final shape of the structure.

The military has shown an interest in tensile structures not only for their portability and ease of deployment, but for their ability to provide large enclosure with a minimum quantity of material as required for radar domes in remote locations. The use of tensile structures in industrial settings, where architectural aesthetics is of limited importance, is just now beginning to be studied. This may be the result of a number of reasons including the perception that tensile structures are too aesthetic for industrial use, competition from existing low cost industrial building systems and lack of a breakthrough project where the unique properties of tensile structures are used to accommodate a specific industrial process. It is our opinion that this project will meld the advantageous properties of tensile construction to the unique demands of ship repair and construction in dry docks to produce a cost-effective industrial enclosure where function rather than aesthetics is the fundamental design consideration.

Tension Fabric Structures - How They Work

Tensile structures can be differentiated from conventional buildings by their contrasting means of achieving stability through tension rather than compression. Using lightweight, flexible materials, tensile structures rely on surface shape and tension to provide enclosures for very large spans. Conventional buildings are constructed of compressive materials like bricks and mortar or concrete and rigid steel frames but tensile structures are built of fabric, cables and flexible, lightweight frames. Tension in tensile structures begins in the highly flexible fabric surface and is transmitted to frames and cables and finally the through anchors to the foundation. Tensile structures respond to dynamic loads by deforming in a manner that actually increases their resistance to such loading. This ability to *give* or deform under wind and snow loads is a key to understanding a tensile structure's unique structural adaptability to dry docks.

Conventional compressive structures rely on two main properties, gravity and rigidity to carry loads. Rigidity is the stiffness needed to resist bending or buckling when materials are in compression. These properties lead to a conventional buildings rectangular shape.

Conversely, tensile structures built of lightweight, flexible materials rely on surface shapes and tension as the main properties for stability. Tensile forces must be transmitted uniformly between continuous boundaries of the fabric as demonstrated by a soap film. A soap film, to exist, takes a shape where tension is equal in all directions across its surface achieving equilibrium of forces for a very specific load condition. Changes in the load on a soap bubble result in deformation of its shape to increase resistance. The shapes that provide for the most efficient transfer of tensions in equilibrium are curved. When the conditions change, so does the shape or curve of the soap film.

Like a soap film, tensile structures have only one shape for any particular set of conditions or loads that produce the equilibrium of forces required for stability. As applied loads increase or change, the shape of the tensile structure changes to regain its equilibrium of tensions. As the shape changes, or deforms, to increased loads the internal tensions also increase resulting in increased stability of the entire structure. A tensile structures then, increases its strength in response to applied loads and is curved in shape to efficiently balance opposing tensions across its surface. A good example is the Denver airport's 377,000 sq.ft. tension fabric roof that reportedly is designed to flex as much as five feet when buffeted by high winds and snow accumulations.

It is this dynamic response to applied loads that makes tensile construction suitable for cost-effective enclosure in floating dry docks. By constantly redefining its shape in response to external loads the tensile structures is able to span large areas with a minimal mass of material.

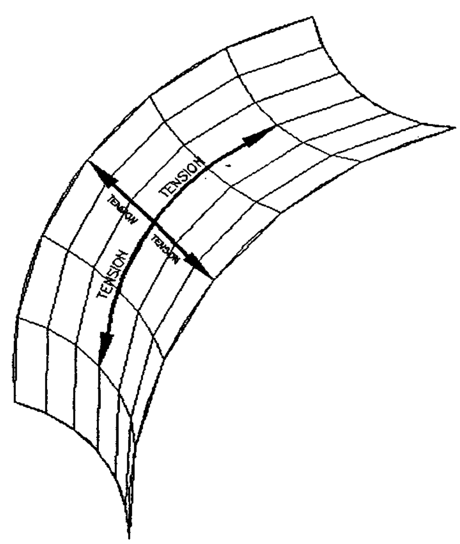
Prestress & Shape

The two most important considerations in designing tensile structures are the effects from wind and snow loading. Dead loads and seismic loading are minimal concern since the total weight of large span structures utilizing the tensile methods can be as low as 2 lbs./sq.ft. Regardless of their shape, all tension fabric structures consist of a minimum of two basic components. These are:

1. The covering fabric that must be constantly held in tension in two directions (equilibrium of tensile forces).
2. The structural framework necessary for holding the fabric in enough tension that it will not flutter during high winds or be permitted to sag when subjected to snow accumulation.

The most practical way of making a thin, flexible membrane sufficiently stiff and flutter-proof is to introduce tension through a combination of curvature and pre-stressing. The deliberately induced curvature enables the membrane to transmit lateral loads, which it could not do when flat. The purpose of introducing prestress is to ensure that the fabric remains in tension, and therefore stable, even after the application of non-uniform loads such as wind buffeting, snow accumulations and wind uplift. The prestress must be high enough, usually about 1,000 lbs. per meter width of fabric, never to be reduced to zero by opposite external forces.

Another key concept to understanding the stability of tensile structures is that of double curvature in opposite directions. Achieving equilibrium of forces in a membrane is easy to understand in a dome or soap bubble shape, but any other shape requires opposing curvature to equalize tensions in all directions. The following sketch demonstrates the double curve or saddle-shape typical of many tensile structures.



EQUILIBRIUM OF TENSILE FORCES

As the sketch of opposing forces suggests, the more curved the surface, the more effective will the prestress perform as a means of providing surface stiffness and preventing flutter. Rates of curvature across the fabric surfaces should be relatively uniform. Large variations can lead to soft areas in some places and stiff areas in others, which is very undesirable.

Edge Restraint

As discussed above, the fabric panels in a tensile structure must have their shape defined by a continuous boundary that will provide efficient transfer of tensile forces to the supporting structure. The requirement for continuity of this boundary can be demonstrated by how soap films stretch across a boundary. If there is any break in the boundary, the soap film instantly ruptures.

For a tensile structure, the boundary may be straight or curved. Where curved, the boundary is often formed by cables sewn into continuous pockets of the membrane. Where straight, the boundary can be defined by rigid clamping plates bolted to the structure or channels formed in the rigid structure into which a rope pocket or luff is slipped much like a sail and mast assembly.

In conventional tensile structures it must be remembered that whichever boundary system is used, the shallower the perimeter curve, the greater the tension that must be applied to the perimeter cable or supporting frame. Higher tensions lead to higher costs and the need for stronger foundations or anchoring. However, greater curvature leads to deeper section depth, which increases the surface area of fabric as well as takes up valuable wing wall space.

These are the boundary and edge considerations for a tensile structure that must be adapted to the rectangular shape of a dry dock. By utilizing the enormous built-in strength of typical dry dock wing walls and deck systems a substantial portion of the upward and downward live load reactions can be delivered directly into the dry dock's internal bracing system with only a minimum amount of structural modification. However, the valuable workspace of the main deck between a dry dock's wing walls must not be overly impacted by diagonal bracing or wide supports for vertical masts.

A Flexible Support Structure

The challenge of providing continuous edge restraint to an inherently curved system anchored to a rectangular dry dock platform is what prompted an investigation of strong but flexible, composite fiberglass masts. These composite masts would be capable of being curved together at the top under tension as a means of quickly enclosing a vessel and the total work area surrounding it. A method for introducing prestress with an opposing curve to the formed arch is required to resist active live loads and must respect the limited space available for this purpose.

To counteract the space demands of deep curvature, the shape of the fabric may be flattened. However, the resulting loss in the fabric's stiffness or rigidity must be made up for by increasing the pre-tensioning forces across the fabric. Continuous grooves will be located on both sides of each flexible mast to efficiently grip the polyester rope sewn into the edges of the panels as tension across the sheet is applied and to allow easy insertion or removal of individual fabric panels when tension is released.

Regardless of whatever structural support system is eventually selected, the rigid elements in tensile structures must be strong, lightweight, and readily available, while at the same time being easy to fabricate, transport and erect. Structural steel satisfies these requirements except for its inability to be repeatedly submerged in salt water unless thoroughly protected by painting or galvanizing which requires careful application and maintenance. Aluminum is a prime candidate to replace steel in lightweight structures. It comes with similar strengths, weighs one third of steel, and is considerably more resistant to corrosion in marine settings. Fiberglass, carbon fibers and other synthetic materials have begun to appear on the market as an alternative structural-framing product. It is their ability to flex without the loss of strength that gives fiberglass composites the edge over either steel or aluminum.

Snow and Wind Loads:

For most dry docks, wind loading will be the largest single factor determining design of the proposed tensile structure. Tensile structures in Japan must contend with typhoon velocities of up to 216 mile per hour and snowdrifts exerting 92 lbs./ft 2[3].

Calculating wind loads on tensile structures is difficult, if not impossible, using conventional analysis because of their typical curved configuration as well as the constantly changing shape in response to varying wind and snow loads.

Current practice for evaluating behavior of tensile structurs relies on experimentation in wind tunnels and computer analysis to solve non-linear, shape finding problems which account for a tensile structures deformation under load. Shape finding is a complex analysis for determining the equilibrium shape of a membrane where all of the tensile forces are balanced as the result of specific applied loads.

Tensile Strength of Fabric

For tension structures, the greatest concern is the tensile strength of the fabric selected to keep out wind, rain, snow and contain airborne emissions from production activities. These external, live load forces can occur either individually, simultaneously, steady or intermittently and over a wide range of intensities as well as duration. Regardless of how

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[3] Technical Standards for Specific Membrane Structure Buildings. The Membrane Structures Association of Japan. January 1996.

these forces might impact the total surface area of the enclosure, the fabric panels themselves must be prestressed tight enough that they neither loose shape or are allowed to flutter.

The deliberately imposed prestress applies tension to the fabric in two directions. Of these two forces, the one designed to exert the highest tension within the fabric is the one applied longitudinally along the length of the fabric as it produced in the weaving process. This direction is known as the "warp". The term "fill" is used to describe the direction of the transverse weave that is placed 90 degrees from the longitudinal warp.

Fabric panels must be oriented so that the warp or longitudinal warp of the fabric is in line with the direction of the highest anticipated forces likely to be delivered to the fabric.

The most basic measurement of a fabric's capacity to support an external load is its strip tensile strength. Strip tensile strength is measured on narrow strips of fabric pulled in a testing machine where the load is applied in a few seconds. In a woven fabric material there are two different strip tensile strength values resulting from the bi-directional nature of the weave. Accurate prediction of the amount of fabric stretch, or creep, in both directions is essential to construct a functional tensile structure.

Based on common design parameters for tensile structures, there are three external forces acting on tension fabrics:

1. Permanently sustained loads such as the applied tension necessary to achieve and maintain prestress. The generally accepted rule for setting the safe allowable fabric stresses for permanent loads is to use 1/8 of the tested strip tensile strength of the virgin material.
2. For wind loads where peaks are generated by short-term gusts, maximum design stresses of ¼ of the strip tensile strength are safe since there is zero sustained load impact.
3. For snow loads, which can be applied incrementally and which have a 50-year peak that can last for several weeks, 1/5 of the strip tensile strength has been adapted as the appropriate allowable stress.

These are the design parameters in common use where the edge of the tensioned fabric panel transfers its load into the surrounding structural frame. The resulting load, as it crosses the connection between the two components, is commonly measured in "pounds per lineal inch" or pli.

The Tensile Design Process

By observing a number of existing tensile structures, the casual observer may conclude that this form of construction results in "free form" structures. This is not the case, however. The properties of modern fabrics and materials and their behavior in relation to the physical principles that provide strength and stability require very specific shapes for acceptable performance of a tensile structure. Each tensile structure has only one shape that is stable under loads and that particular shape is determined by the limitations of the materials used.

The dynamic response, or deformation, of tensile structures to live load require specialized computer software to solve non-linear finite analysis to find the precise shape that will conform to the physical principles of tensile structures. A complete understanding of the behavior of selected materials and fabrics is also required to accurately shape panels and components that will preserve equilibrium of tensile forces during deformation. As verification of the complicated mathematical modeling of tensile structures, physical models are constructed and exposed to wind tunnel analysis to verify overall structural response to live loads.

Only a hand full of firms around the world have developed the necessary expertise in the diverse specialties required to successfully shape and analyze a tensile structures. The remaining objective of this project will be to integrate current tensile construction methods with the innovations developed in this project to develop an enclosure system useful on dry docks.

Section 6 Structural Support for Tensile Structures on Dry Docks

Tensile structures require curvature to establish equilibrium of forces across a fabric membrane's surface. The structural system defines the shape and degree of curvature. Dry docks are not designed for enclosure and most horizontal surfaces are either cluttered with operating equipment or dedicated to support of the repair processes that occur in dry docks. Thus, the structural support systems for enclosure of floating dry docks must be carefully planned so they do not impede ship repair processes, be located in harms way, or impede operation of the dock.

Other challenges exist to dry dock enclosure include:

a) Crane access must be provided for. This may be accomplished by using a sliding cover that moves in horizontal or vertical direction;

b) Mechanical parts used to operate a moving structure and /or a sliding cover must be simple, robust, and require low maintenance;

c) The structural system must support the weight of the enclosure, wind and snow load, and any internal cranes or supports for ship's services or access;

d) The structure must span the dry dock width and provide sufficient overhead clearance for that portion of the dry dock's service fleet that is targeted for enclosure;

Later discussions will provide the reader with a comparison of the basic properties of probable construction materials that are likely to be used to construct a dry dock enclosure. This section will also provide the reader with a description of how these materials could be arranged to create structural members capable of achieving a, light weight, cost effective structure over a floating dry dock. The final part of this section will provide the reader with an overview of some of the concepts for arranging the structural members in a way that will provide the functionality required of enclosure over a floating dry dock.

The Foundation

There are two broad approaches for providing a foundation for the enclosure of a floating dry dock; 1) conventional such as earth supported piles, drilled piers or spread footings or 2) the floating dry dock itself.

Conventional foundation systems will allow construction of large, massive structures capable enclosing both the floating dry dock and the largest ship intended to occupy the dry dock. With a conventional foundation system, both dead and live loads are transmitted to the earth independent of the dry dock and vessel system. Conventional construction methods can be employed to accept dynamic load differentials as will be introduced from the movement of rail mounted sectional buildings or bridge cranes supported by the enclosure structure. From an engineering perspective, earth based foundation systems simplify the task of enclosing floating dry docks, however, the high cost of underwater construction and maintenance as well as the cost of providing an enclosure capable of accommodating the largest vessel the particular dry dock is capable of lifting may result in unreasonably high capital costs. For shipyards with dry docks surrounded or partially surrounded with earth based structures such as cell walls or piers this may be a reasonable approach.

The second alternative for an enclosure involves supporting the system on the existing floating dry dock. It appears that this second choice may be more efficient in terms of span width and overall mass of the proposed enclosure. However construction of this type of enclosure will be complicated by the docking evolution of lifting and launching ships and the production processes of ship repair that must occur unimpeded by the proposed enclosure system. The ship, the dry dock, the enclosure, and the repair processes that impinge on these three structures comprise a system that must work in harmony to create a net increase in productivity. Enclosure, by itself, for this application should be relatively straightforward. Accommodating the numerous processes involved in the vessel lifting, launching and repair presents significant complications. If this alternative is implemented, it will be a challenge to achieve an overall net gain in productivity without negatively impacting production in ship repair. Since this alternative is the most efficient in terms of overall mass required to achieve enclosure, but more challenging in terms of impacts on productivity the focus of this section will be on dry dock mounted enclosure systems.

Based on work productivity and assuming minimal enclosure maintenance problems, it appears the most efficient enclosure system will be permanently mounted to the dry dock and configured to accept the largest vessel in the selected service fleet. The service fleet for which the enclosure is intended to accommodate may not include the largest vessel that the dry dock is capable of lifting. A cost analysis may show that an enclosure for, say, the largest 10% of a particular dry dock's service fleet is not cost effective. If this is the case, then the enclosure system may need to be either retractable or removable to provide clearance for larger vessels.

The Floating Dry Dock

Because this project brings the architectural and structural engineering disciplines together with shipyard practices and dry dock design, a brief description of a floating dry dock and its general operating principle is presented here. Figure 1 depicts the section and outboard view of the Ketchikan Dry Dock #1.

Floating dry docks are essentially submersible barges with vertical wing walls. The vertical wing walls provide wing wall deck space that remains above water when the dock is in the submerged position. Equipment that is typically found on a wing wall deck includes ship's centering equipment, the control house, cranes and ship's services. Ship's services are the utilities that may be required by the ship during its repair period in the dry dock. Ship's utilities include power, water, steam, and sewer. An airtight space called a safety deck exists in the wing wall immediately below the deck. This safety deck provides reserve buoyancy in the submerged position and it is used to keep the dry dock afloat during events such power outage or other condition that may delay or halt the docking evolution

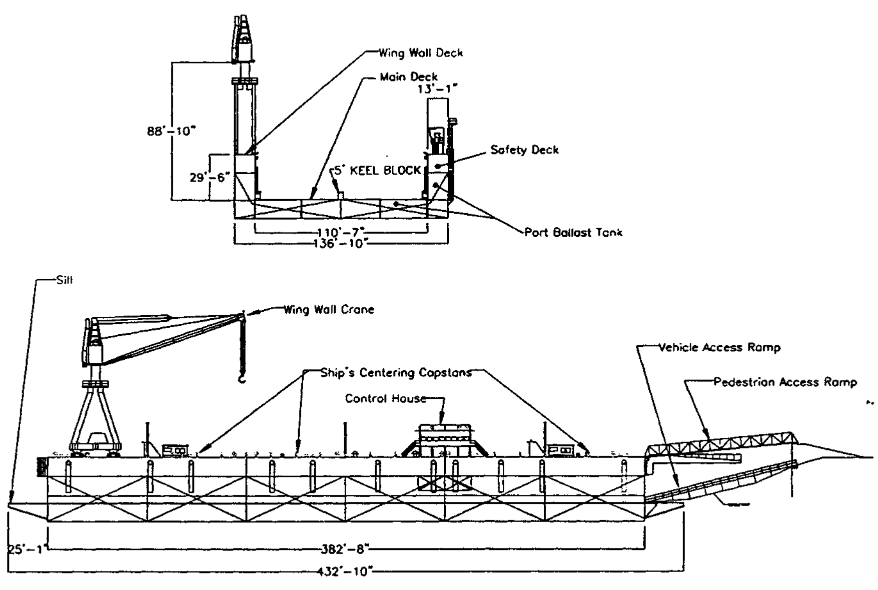

Figure 1: A Floating Dry Dock

The docking evolution begins with the lowering or submerging of the dry dock. Flood valves are opened and ballast chambers are flooded until the main deck is submerged to the desired depth. Then the flood valves are closed. The ship is then escorted by tug to the sill of the dry dock where mooring lines are passed from the wing wall to the vessel and made fast to cleats on the ship. Ketchikan's ship's centering system is composed of a series of capstans located at strategic points along the dry dock. The capstans take tension on the ship's mooring lines pulling the vessel into the dry dock. As the mooring lines come abreast of the capstans new mooring lines are engaged on the next set of capstans and the winching of the vessel forward continues until it is positioned over the keel blocks upon which the vessel will rest.

When the vessel is properly positioned so that sea chests, keel coolers and other ship's underwater equipment is clear of the keel blocks, ballast pumps begin evacuating the ballast tanks and the dry dock floats back to its raised position lifting the ship clear of the water ending the lifting phase of the evolution. As the dry dock is being raised the dock master may introduce hog or sag into longitudinal orientation of the dry dock. Hog or sag, bending of the dry dock along its length, is allowable up to certain limits specific to each dry dock.

The next phase of the evolution commences with repair processes. The focus of repair work in a dry dock is on the underwater portions of the ship. Typically, sea valves and propulsion systems are serviced in dry dock. The hull is usually pressured washed immediately after lifting and necessary steelwork begins. Surface preparation and coating of the hull is a common dry dock task occurring at the end of the dry dock repair cycle. Wing wall mounted cranes are often used to assist with these repair processes. Other equipment used in ship repair may consist of gas, diesel or propane powered equipment such as man lifts, fork lifts, welders and transport vehicles.

Upon completion of the repair cycle, the ship is inspected for watertight integrity and the launching cycle begins. The ballast tanks are flooded, the dry dock sinks, and the vessel is backed out of the dry dock using capstans and mooring lines until tugs can take over ending the dry dock evolution. During both the lifting and the launching cycle of the docking evolution, windy conditions can threaten to drive the ship into the inside face of the wing walls. The designer of the dry dock enclosure must be aware of the potential for damage to the foundation structure that is used to support the enclosure. For example, the foundation would be vulnerable if the foundation structure is attached below the wing wall deck along the inside face of the wing wall. Further, the structure may be damaged by overhead interference caused by the ship's upper decks.

The designer must consider the added horizontal loads and their influence on the dry dock moorage system. For example, the dry dock moorage system is used to änchor the dry dock in position. The increased sail area of the proposed enclosure will cause an increase in horizontal loads. These are the loads that must be considered.

Foundation Options

Having focused on the floating dry dock as the basis of foundation for the proposed enclosure two different approaches to supporting the structure now evolve. These are:

- Enclosure supported entirely by the floating dry dock ;
- An enclosure partially supported by the dry dock and partially supported by the docked vessel.

The following illustrations show the choices of foundation arrangements for dry dock mounted enclosures.

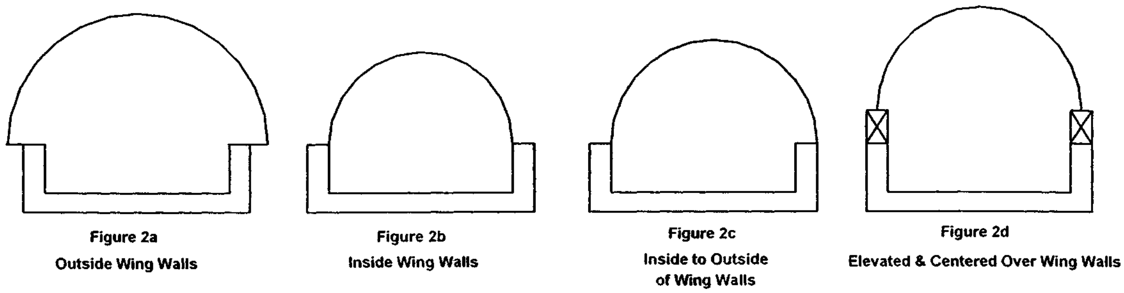

Figure 2: Enclosure Foundation Mounting Points

Figure 2a shows an enclosure foundation that is constructed on the outboard side of the wing walls. Advantages of this mounting location include unobstructed access from both wing walls to the production area and the ship, minimizes interferences with the dry dock evolution, moves the enclosure's foundation and mechanical systems out of harm's way, and minimizes intrusion into production area of the main deck. Disadvantages include interference with wing wall mounted cranes and the additional span width resulting in a larger enclosed feet print. The availability of adjacent pier structures oriented longitudinally to the dry dock and capable of supporting service cranes for dry dock may make this a viable option. If the service cranes are located on adjacent piers, the enclosure must be retractable to provide for crane service. Internal crane service is possible in this alternative, however, the enclosure would need to be sized to provide additional overhead clearance.

Figure 2b shows the enclosure foundation mounted to the inboard sides of the wing wall. Advantages of this location are: it preserves use of wing wall mounted cranes, it minimizes span width; and the overall enclosed footprint is reduced. Disadvantages are: a) It does not provide for crane access to the vessel and dry dock deck, b) protection of the enclosure foundation structures is not provided and this may cause interference with the docking operation, and c) this may have the potential for causing obstructions to ship's services and personnel access. Constructing the foundation structures inside the ballast tanks may provide protection during dry dock evolution and avoid encroachments on the production area between wing walls. Figure 2c illustrates a foundation structure that is located on one inboard wall and one outboard wall. This configuration is a possibility for dry docks with one wing wall crane like the Ketchikan Dry Dock #1. Access for gangways and ship's services are protected on the enclosed wing wall side. Disadvantages include oversized footprint over wing wall deck.

Figure 2d shows false work that could be used to raise the enclosure foundation above the existing wing wall deck. This option allows the designer to use any of the other foundation arrangements while minimizing the respective disadvantages. The advantages of raising the foundation mounting points above the existing wall decks include:

- Minimal impacts to existing wing wall mounted equipment, i.e. capstans, ventilation systems, ship's services, control houses, etc. Wing wall mounted cranes could be raised to travel along the new top deck.

- Creation of an unobstructed mounting surface free of the usual equipment normally found on the top deck of a wing wall.
- Foundation falsework contributes to vertical sidewall of the proposed enclosure.
- Minimizes required enclosure span width.
- Provides clearance for enclosure operating equipment and membrane storage.
- Removes enclosure operating equipment and foundation components from damaging environment that exists below top of wing walls, i.e. ship impact and frequent salt-water immersion.
- Enclosure membrane can be mounted on outside of foundation leaving inside aspects open to accommodate ship centering system and temporary services.

- Disadvantages of this alternative could include potential negative impacts on the longitudinal stiffness of the dry dock and, due to the extra elevation, excessive height to peak for dry docks that have relatively low overhead clearance requirements.

The use of the ship in combination with the dry dock to enclose the work area provides another alternative foundation system that is worthy of consideration. In this approach, the ship's top deck is enclosed. This may mean that ship mounted enclosure technology could be adapted for this application. Current shipyard practice for this type enclosure employs scaffold sections and shrink-wrap or other membrane systems secured to a constructed scaffold frame. Development of a modular component system where enclosures can be quickly constructed and removed with reusable materials will make this approach more viable. The underwater body portion of the ship would be enclosed by a system that would mount to the inboard face of the wing walls and extend to the main deck of the ship. Consider that this enclosure strategy may be more appropriate for use in repair yards. It could provide a readily available, rapidly deployable enclosure for the underwater work and an enclosure system for the top decks that could stay with the ship when it is relocated to a pier side berth where top deck work could continue in a protected environment, see Figure 3.

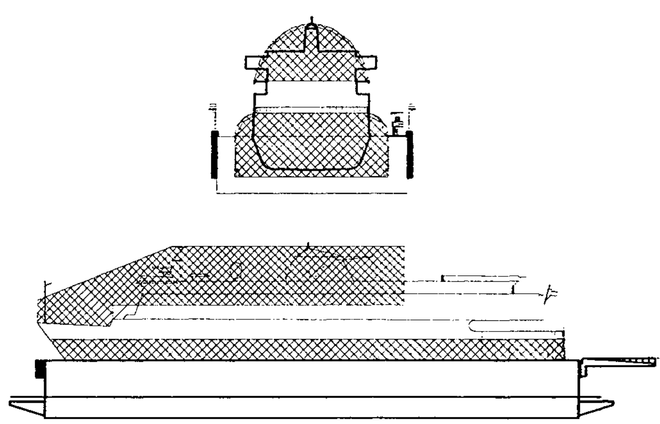

Figure3
Combination Ship & Dry Dock Mounted Enclosure System

Figure 3 shows an enclosure where the foundation support is provided by both the dry dock and the ship. This system appears to have several significant advantages. If this system is compared with a full enclosure, the structural span width is significantly reduced. This means the enclosure mass is reduced. Dry dock modifications needed to provide a foundation would be minimized. Further, the added sail area caused by enclosing the vessel will not be much different than the exposed area of the vessel. This also minimizes the impact on the dry dock stability and structural modifications needed for anchoring. Only those areas of the top deck requiring enclosure need to be enclosed.

This is the most efficient enclosure system (only that needed to conduct work will be enclosed, so less mass, less modification, and less structure). However, this system will provide a greater engineering challenge and the costs associated with deployment may be greater. Conventional primary structural members may be used to span between the wing wall and the vessel. Mechanical details needed to enclose both the upper deck of the vessel and to enclose the underwater body appears to be feasible. Deployment of trusses, or in this case booms, can be accomplished in a number of ways using cranes or fork lifts to assist with system assembly. A more automated approach would involve mounting mechanically activated articulating or extendable booms on the inside of the wing wall. If false work is added to the top of the dry dock wing wall, cable and pulley systems can be used to deploy the booms. The varying geometry that will result between any two pair of booms will provide challenges in deploying the cover, e.g. fabric panels. Unless the supporting boom extends over the main deck of the ship, a weather seal between the enclosure and the ship's hull will need to be engineered. Others have begun addressing this issue. For example, Rapid Deployable Systems, L.L.C.[4] is developing a seal for its ship containment system

Types of Tensile Structures

The Membrane Structures Association of Japan has published Technical Standards for Specific Membrane Structures,[5] which provides some useful definitions of different types of tensile structures.

1. *Frame Membrane System*
   A structural method for forming roofs or external walls by membrane materials on the rigid steel framework or other framework.
2. *Suspension Membrane Structure*
   A structural method mainly using membrane material and having a basic form of suspension structure

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[4] Rapid Deployable Systems, L.L.C., 2061 Avenue B North (upper), North Charleston, SC 29405, web address "sasles@rapid-ds.com"

[5] The Membrane Structures Association of Japan. Technical Standards for Specific Membrane Structure Buildings. The Membrane Structures Association of Japan, January 31, 1996

3. *Air-Supported Membrane Structure*
   A structural method in which air is supplied into the indoor space enclosed by a roof and external walls formed using membrane materials in order to increase the air pressure within the structure to apply tension to the membrane materials, and thereby provide the structure with resistance to load and external forces.
4. Retractable Membrane Structure
   A frame membrane structure or suspension membrane structure allowing all or part of those portions of the roof, walls or both made of membrane materials (hereafter referred to as "roof, etc.") to open and close. The terminology used to express the open or closed state shall include "open state," which means that the roof, etc. is open, "running state," which means that it is moving, and "closed state," which means that the roof, etc. covers the interior of the structure
5. Membrane Materials and Fixtures Thereof
   Roof and external wall made of membrane materials, and the wire rope, synthetic fiber rope stainless steel wire, fixing hardware, and other similar parts used to support or to reinforce this roof and wall membranes material.

As the range of enclosure concepts move from the *frame member structure* to the *suspension member structure* fewer components of the overall structure act in compression and more of the components are under tension. This section identifies enclosure concepts that fall into the *frame member structure*. Section 8 will describe *suspension member structures*.

Section 7 MATERIALS OF CONSTRUCTION

A successful enclosure for use with floating dry docks will require an imaginative use of materials and structural ingenuity. This means the enclosure must have mechanical functionality so that ship repair can be carried on without loss of production. A reasonable capital cost will probably lead to a widespread use for ship repair.

The following table, Table 1, provides the relative values for several properties of conventional and recently available engineering materials that are often used in building construction. The choice for the enclosure structure will probably depend on: a) strength-to-weight ratio; b) expected maintenance costs; and c) capital costs. The final decision will be part of the engineering solution.

Material	Weight lbs/in³	Wt: % of steel	Strength Ksi	Corrosion Resistance	Comments
Steel, A36	.284	100%	30-150	Surface Prep & Coating	Conventional steel
Aluminum	.095	34%	14-55	Good	
Wood (Fir)	.019	6.5%	2.4	Good	Only one of many types of timber
Pultruded Fiberglass	.062-.070	22% - 25%		Coating for U.V.	Materials are anisotropic, light, strong, but must be UV protected.
Advanced Composites					Materials are anisotropic, light, strong, but must be UV protected.
Fiberglass/Epoxy	.072	25%	16	Coating for U.V.	
Fiberglass/Carbon/Epoxy	.072	25%	29	Coating for U.V.	
E-glass	.072	25%	500	Coating for U.V.	
S-glass	.072	25%	600	Costing for U, V.	
Kevlar	.050	17.6%	500	Coating for U.V.	

Table 1: Properties for Selected Construction Materials

The mechanical and physical properties of wood, steel, and aluminum are well understood by the shipbuilding industry. Any shipyards that might consider an in-house design and construction of an enclosure will be familiar with conventional materials. Pultruded fiberglass, carbon fiber, plastics and other advanced composite materials are worthy of consideration for use in providing a light weight structural system for the enclosure. This material has a high strength to weight ratio, good corrosion resistance and easily workable with conventional tooling. Thus, pultruded fiberglass is a candidate for the enclosure structure. Other materials for consideration may include high performance steels.

Enclosure Framing

The use of fabrics in architectural applications has led to the development of a wide range of framing schemes for tensile buildings. A tensile structure is distinguished by the minimal use of components that act in compression. Principle tensile framing components are often cables supported by masts that act in compression. The construction of a tensile structure has the advantage of a relatively small mass of material required to provide enclosure. Fabric structures are often found in pre-engineered, pre-manufactured buildings. Framing systems in these structures transmit forces to the foundation through their compressive strength and the fabric is stretched over the frame with enough tension to resist serious flutter. The weight of the membrane and the live loads acting on it are transmitted through the rigid framing system that acts in compression. In this type structure, the framing system is the dominant or major component of the building. At the other end of the scale, as the structure becomes more tensile, the compressive framing system becomes less dominant. In these schemes the fabric, cables and tubing transmit tension to widely spaced trusses or columns where the forces are transmitted to the foundation under compression.

A member that is being squeezed or shortened with an axial load is said to be in compression. The load capacity of a compression member depends on support conditions, shape and length. A long member needs to be checked for buckling or stability. If a member is being stretched with an axial load, it is said to be in tension. A member that carries a transverse load will try to bend; this type of member is a beam. Most structural members are subjected to have both axial load and bending. The type of member depends on load and the structural system. Further, to understand the nature of compression and tension in a structure, consider the source of the force. Compressive forces are the result of gravity effecting the arrangement of building structure to achieve stability. Tensile forces are the result of mechanically induced energy acting on the structure to achieve stability. These tensile forces can be the result of service loads resulting from uplift caused by aerodynamic roof shapes, wind or snow pressure, or through tension mechanically applied to cables and membranes to counteract service loads like wind and snow.

Trusses and Frame Sections

Structures are often built using trusses, frames or combination. Consider a truss. The simplest stable truss is a triangle. This triangle has 3 members and each member is connected with pins or bolts. A truss member is assumed to only resist axial loads; it is often called a two-force member. Two force member means the member has an internal axial force at each end. These forces may cause compression or tension. Any structure that relies on truss members must rely on triangles to distribute load. A frame member is capable of resisting axial load and moment. These members may be put together in any configuration and often rely on welds to transfer forces between members. A bolted joint using a stiff back member to transfer moment around the joint can also be used.

A paste board box is an example of a four chord member. If the corners are rigid, the box is able to carry quite a load. However, slice the corners with a razor blade, and the box will collapse. This example illustrates that a truss must be formed using triangles. The sketches in Figure 4 show section views for three simple structural systems. The first view illustrates a two-force axial member; this member may be used in a truss. The 2 force member has a widespread application in pre-engineered and pre-manufactured fabric covered structures. The two force member is well suited for this heavily marketed product because it can be manufactured in modular sections and shipped in compact units to remote job sites where they can be quickly bolted together and assembled into a completed structure. Its application should be restricted to trusses or bracing members. If used in a truss, it may be assembled in triangles such as the 3-chord truss illustrated in Figure 4. This 3-chord truss is often part of a space truss. The 2-force member has very little lateral strength by itself resulting in relatively narrow frame spacing and a considerable number of bridging components to provide lateral strength. Because of the resulting "web" of fixed structural members, deployment schemes for structures using this truss form will be limited to rail mounted longitudinal nesting schemes where the entire segments of the structure are moved to provide openings necessary for crane access. The joints in the 4–chord frame shown in sketch 3 must be rigid. This means welded or bolted so moment is transferred around the corner.

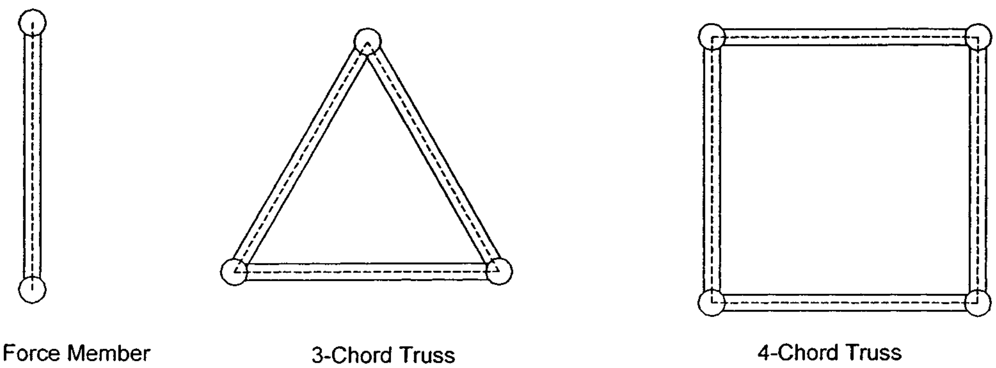

Figure 4: Truss Sections

Figure 5 below shows a Rubb Building Systems[6] modular structure demonstrating the elements of a frame member structure relying on two force members for stability.

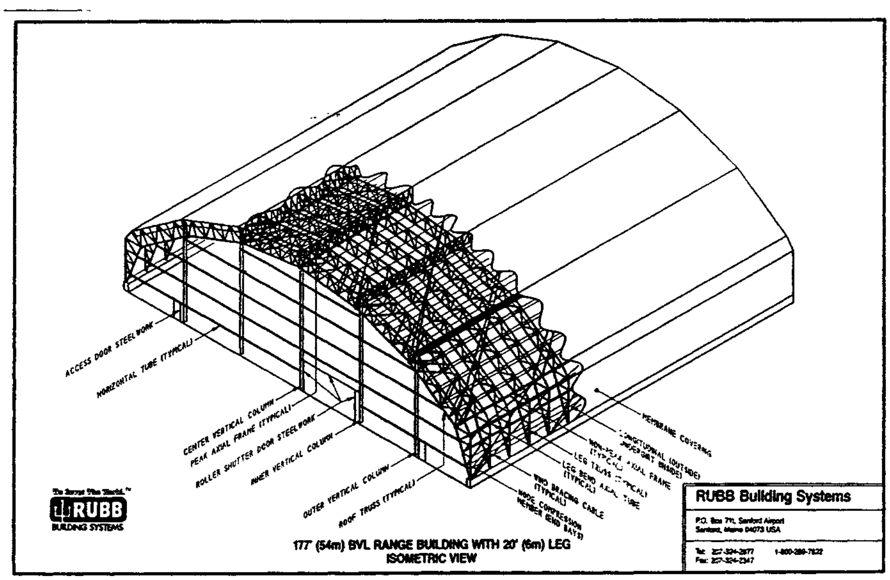

Figure 5: A Frame Member Structure

Because floating dry dock enclosures must open and close, the mechanical functionality, framing systems that minimize or eliminate the web of horizontal and diagonal bridging provide an alternative to moving entire building sections to provide crane access. By reducing the number of trusses to a minimum and eliminating bridging between trusses, the overall mass of the enclosure can be reduced with the use of tensioned structures to complete the enclosure system. Construction of these more pure tensile structures will

[6] Photograph courtesy of Mr. Sid Morrell, Satellite Shelters International, Inc., Rubb Building Systems Northwest, 151 Seton Street, Port Townsend, WA 98368, Tel: (360) 279-9718

require a truss system capable of resisting forces from a multitude of directions. The 3-chord system can become a space truss and the 4-chord system may be used as a space frame.

Figure 6:
3-Chord Truss

Figure 7:
4-Chord or Box Truss

These 3 and 4-chord structural systems will help minimize bracing. Figures 6 and 7, found on the web page www.rollercoasterworld, demonstrates the ability of 3 and 4 chord structural systems to resist multidirectional forces.

The mechanical functionality required for enclosing floating dry docks would introduce a level of architectural complexity that is rarely found in conventional building systems. This complexity is created by the requirement for a lightweight construction capable of rapid reconfiguration. This is needed to accommodate shipbuilding processes. Cranes are used to transfer of material from outside the enclosure to anywhere and everywhere inside the enclosure. This is a particularly troublesome process that must be accommodated by a useful dry dock enclosure. Modern roller coaster design offers another example of a structural system that incorporates both 3-chord truss and 4-chord frame members. Both 3 and 4 chord structural components such as those illustrated above may be useful in the enclosure structure.

The following illustration of a modern coaster suggests a truss system that may provide the strength and weight requirements necessary to achieve cost effective dry dock enclosure. Essentially the truss system can be described as a modified 3-chord truss using a box beam as the primary chord. Tubular stock comprises the two minor chords that can be arranged asymmetrically to provide lateral bracing required for efficient tensile construction. Asymmetry is introduced along the length of the truss as it tapers towards the peak as shown in the tapered shape of the bent and parabolic truss systems shown in the next set of illustrations.

Figure 8
Example of a modified 3-Chord Truss

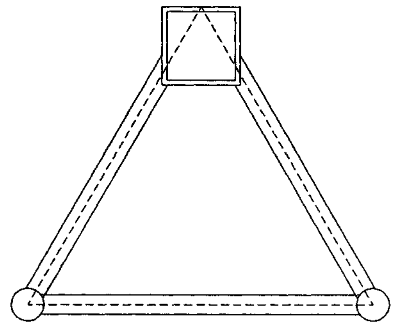

Figure 9
The Modified 3-Chord Truss

Truss Profiles

Having identified some truss sections that can efficiently resist loads in all directions the geometry of the proposed use begins to suggest certain truss profiles or shapes that will efficiently transfer loads from the membrane to the foundation.

Two structural shapes are most useful for enclosure of floating dry docks; the cylindrical arch and the bent truss as illustrated in Figures 10 and 11 below. Structurally the cylindrical arch is the most efficient but for dry docks serving vessels with tall, square top houses, the bent truss system may fit the geometry better.

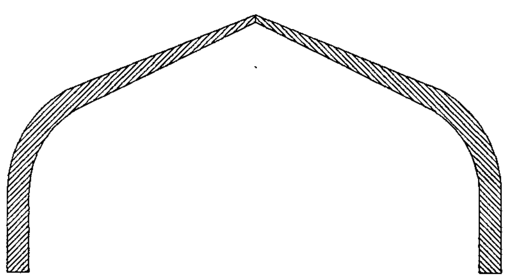

Figure 10
Cylindrical Truss

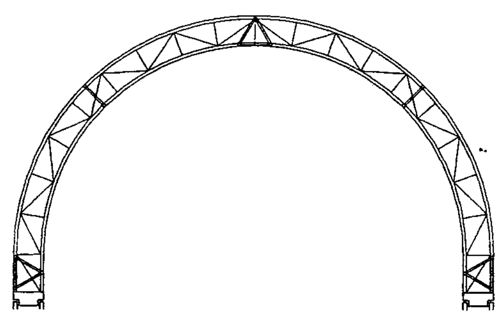

Figure 11
Bent Truss

Parabolic arches have been evaluated for use on the Ketchikan dry dock but the geometry of the dry dock and the vessels served by the dock are better matched by the bent truss or cylindrical arch. The large width to height ratio of the Ketchikan dry dock and the high and wide section shape of vessels using the Ketchikan dry dock result in an unnecessarily high peak if parabolic arches are employed. Nevertheless, parabolic arches do have the advantage of steeply sloped roof section that would minimize the affect of snow loading and the extra sail area may be justified in areas of high snowfall.

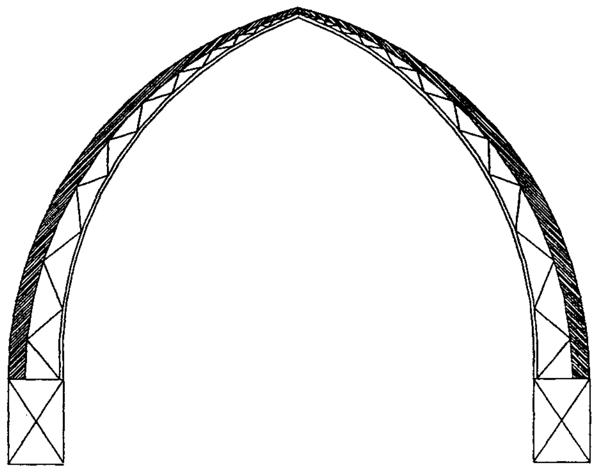

Figure 12
Asymmetric Parabolic Arch

The asymmetry of this truss shape is both in the parabola of the overall shape and in the section of the truss itself; a wide section at the base tapering towards the peak.

Effects of Hog & Sag on Enclosure Framing

Floating dry docks are capable of longitudinal deflection; bending along the length. This longitudinal stiffness is a function of design calculations and material used in construction of the dock. Longitudinal deflection in dry docks is known as *hog and sag.* Hog occurs when the center is higher than the ends. Sag occurs when the center is lower than the ends. Being able to introduce hog and sag into a dry dock is useful for matching the shape of the keel blocks, resting on the main deck, to the shape of older boats that may have developed hog or sag from unequal cargo loads. Whether a vessel is hogged or sagged, the Dock Master carefully monitors longitudinal deflection during lifting and launching events to prevent exceeding the dry docks limits of deflection. Exceeding the limits of deflection will cause the shipyard to work overtime in repairing their dry dock.

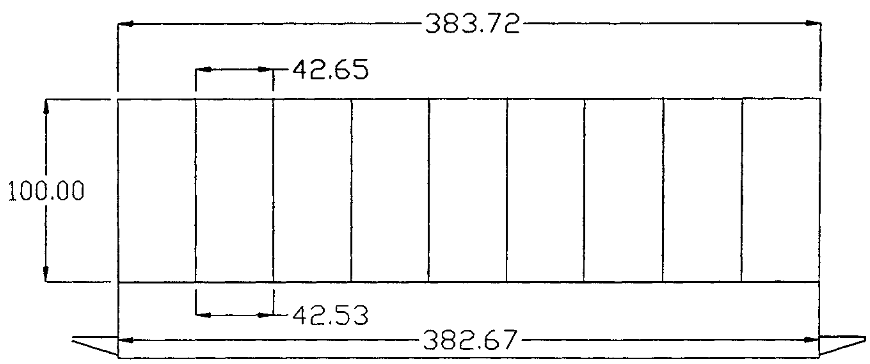

Figure 13: Longitudinal Deflection of the Ketchikan Dry Dock

The Ketchikan Dry Dock #1 is allowed to deflect 6 inches over its length. Figure 13 shows the Ketchikan dry dock hogged to its maximum limit of deflection. The purpose of the drawing is to show the longitudinal deflection between trusses that are 100 feet high with a bay spacing of 42.53 feet. Horizontal deflection over the bay width is 0.12 inch and overall deflection is 1.05 feet. Tensile structures, either frame membrane or suspension membrane, will probably accept this amount of deflection.

Arrangement of Trusses in Proposed Enclosure Concepts

The choice of materials, structural geometry, member type and arrangement for a given dry dock enclosure is influenced by many factors. Some are:

- Availability of land or land based structures immediately adjacent to the dry dock
- Presence of wing wall mounted crane and equipment
- Dry dock geometry
- Geometry of vessels serviced by the dry dock
- Orientation to prevailing weather patterns
- Local building codes
- Maintenance considerations
- Impact on production
- Initial cost

The following enclosure schemes may have potential to be considered as a cost-effective enclosure for a floating dry dock. The list is ordered using an organizational hierarchy that is based on the operational characteristics of the proposed concepts.

1) Fixed Membrane – Horizontal Nesting
    a) Nested systems operate with rail mounted building segments that fit within each other where individual segments are moved longitudinally to provide openings for crane access.
        i) Conventional steel buildings founded on marine structures
        ii) Pre-engineered fabric skinned buildings mounted on the dry dock
        iii) True tensile construction minimizing framing

2) Fixed Membrane – Vertical Nesting
    a) Deployment of fixed membrane systems relies on movement of an entire panel with the membrane remaining under tension as it moves from up or down to provide and open or closed section between trusses.
        i) Tensile Sails
        ii) RFP Panels

3) Flexible Membrane - Horizontal Retraction

a) This system operates by longitudinal movement of the individual frames providing an accordion type action. Tension is applied to the membrane when the system is fully deployed.

4) Flexible Membrane - Vertical Retraction
   a) This system operates by relaxing tension on the membrane and hoisting or lowering the individual sails as is required. The truss system either remains in place or retracts or rotates to provide clearance for oversize ships. Storage of the membrane is accomplished with either folding or rolling mechanisms
      i) Modify roll up door technology
      ii) Tensionable sails between fixed trusses
      iii) Tensionable sails between rotating cantilevered arches
      iv) Tensionable sails between flexible masts

5) End Wall Treatments
   a) Clam Shell
      i) Flexible membrane compresses via upward rotation (accordion action)
      ii) Rigid membrane nesting via upward rotation (lobster tail)
   b) Sectioned Dome
      i) Flexible membrane compresses via horizontal rotation (accordion)
      ii) Rigid membrane nesting via horizontal rotation (lobster tail)
   c) Self furling systems
      i) Sail boat technology

6) Combined wing wall to vessel and vessel mounted
   a) Pre-assembled, crane lifted
   b) Modular wall, roof and membrane kit assembled on vessel

7) Air Supported systems
   a) Pressurized Primary Structure
   b) Pressurized truss system, tensioned
   c) Resistance to live loads limited to pretension , dry dock shapes will generally have high profiles with large lateral loads

The following illustrations provide graphic examples of how the various truss systems and principles of operation.

1. Fixed Membrane –Horizontal Nesting

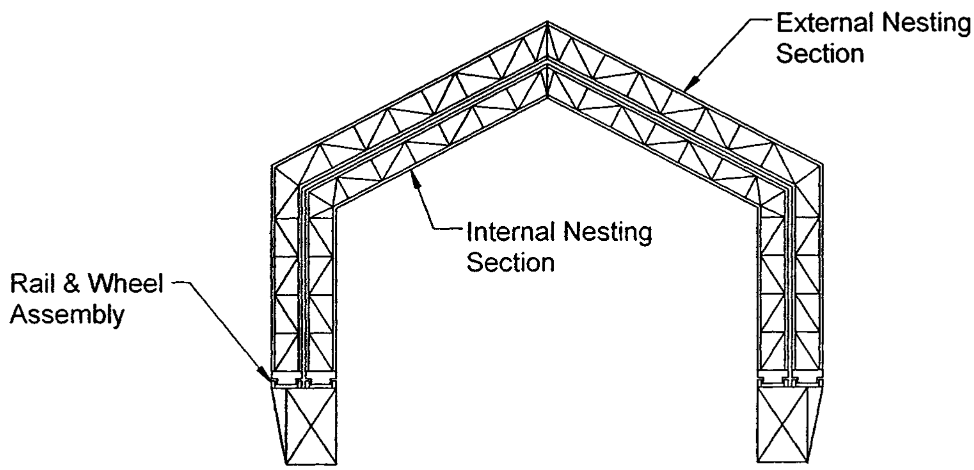

Figure 14: A Rail Mounted Frame Membrane Structure

The weight of conventional steel buildings will require a robust transport system with more wheels and foundation structure than lighter weight tensile structures. Significant differential loading on the dry dock would occur when building sections are nested. Issues to be addressed would include adequate foundation structure in the wing walls and potential re-ballasting.

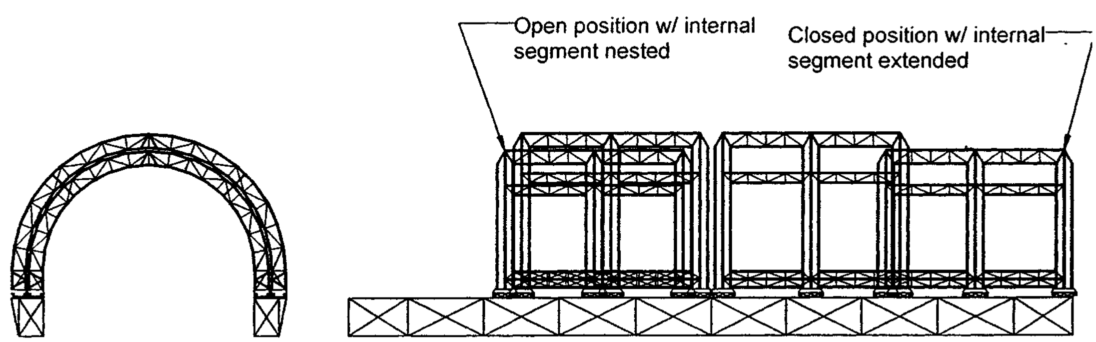

Figure 15: Nesting Cylindrical Arches Open & Closed

The nesting cylindrical arches in Figure 15 represent a double nesting factor. Triple quadruple nesting means that three or four structures are nested. Increasing the nesting factor will add greater compressibility to the overall enclosure allowing it to collapse to one end and to more easily accommodate oversize vessels. Smaller moving sections will decrease the energy required to move the individual sections. Smaller sections may also prove more useful in dry docks requiring frequent crane usage. For large structures, a system must be devised to efficiently move the building sections between the open and closed positions. The use of capstans, common to many floating dry docks may be useful for this function. Once positioned a braking or locking system will also be required to hold the sections in place. This system will need to be robust to counteract the significant wind forces that will be developed on the large sail areas. Both the motion and braking systems will be required when fore or aft list is introduced in the dry dock. Consider a scheme to accommodate oversize vessels. This system might use a rail system to extend the enclosure beyond the end of the dry dock to either land or a pile structure built in line with the wing wall. The entire enclosure could be rolled completely off the dock for storage. The cost of construction pile supported structures or the usual shortage of upland space in shipyards means a larger nesting factor is needed. However, this system offers greater compressibility and would reduce off-dry dock storage areas requirements.

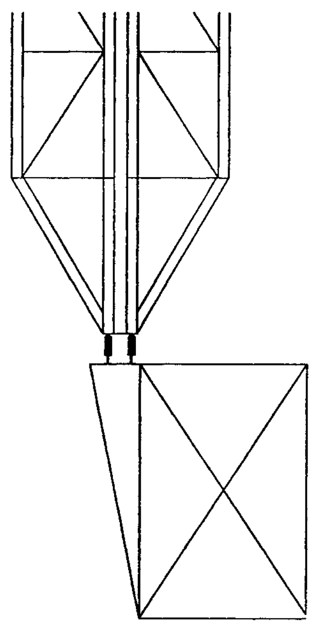

Figure 16: Rubb Building's Rail & Wheel Arrangement
An efficient use of wing wall deck space

Rubb Buildings use a rail and wheel assembly as illustrated above. This scheme minimizes track area that is required for a double nesting enclosure structure. This scheme will be useful for those applications where a nesting enclosure is adapted to the main deck of the wing wall, which is often cluttered with mechanical systems.

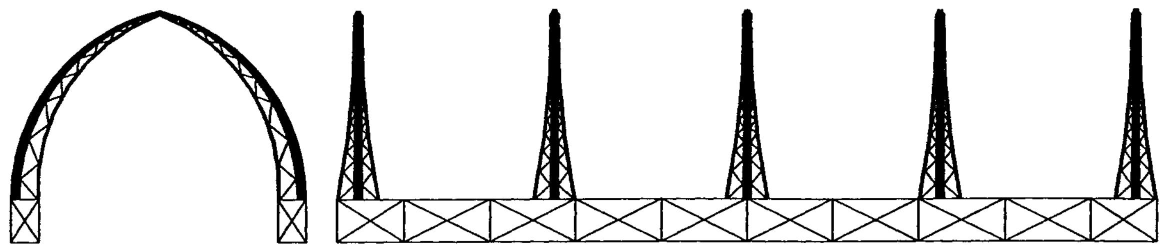

Figure 17: Asymmetrical Parabolic Arches

The asymmetrical parabolic arches shown above are arranged using the modified three-chord truss system described earlier. With wide bases and narrow peaks, this geometric form offers the greatest strength with the least material. By providing great strength, the web of lateral and diagonal bracing required for conventional structures can be eliminated and the number of trusses can be reduced. In this concept the trusses are stationary and the opening are created by movement of the membrane. Use of fiberglass or other composite materials can increase the strength and reduce the weight of the enclosure.

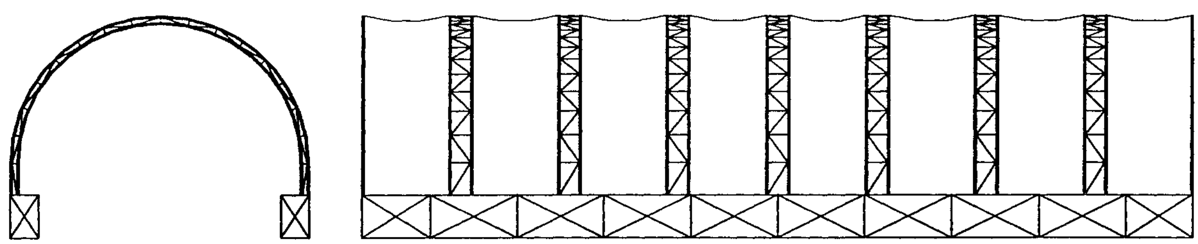

Figure 18: Fixed or Rail Mounted Cylindrical Arches In Closed Position

Figure 18 describes a truss system described in the organizational hierarchy as "flexible membrane – horizontal retraction. Figure 18 show the trusses in the closed position. Figure 19 shows the trusses in the open position. This is the operating principle developed by CMR Environmental Energy Research & Development (CMR)[7].

[7] CMR Environmental Energy Research & Development, 21 Armstrong Avenue, Unit #2, Georgetown, Ontario, Canada, L7G 4S1, Telephone (907) 873-4140

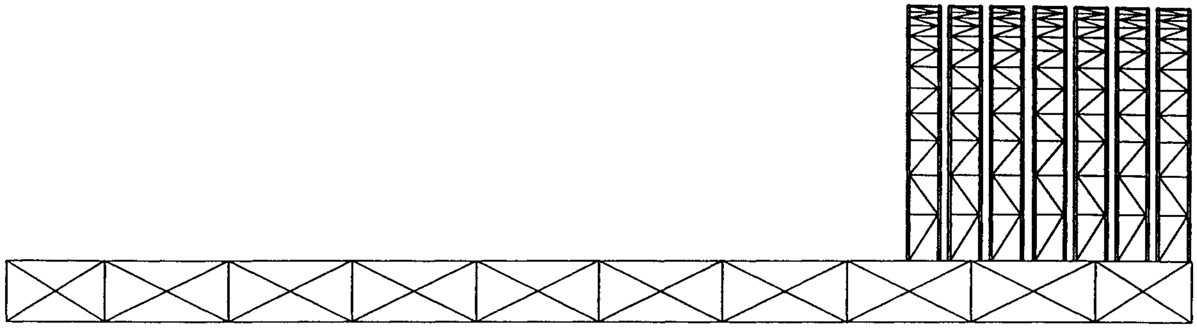

Figure 19: Flexible Membrane Horizontally Retracted in Open Position

When enclosures, as shown above, are retracted to one end of the dry dock to accommodate oversize vessels differential weight distributions must be evaluated to determine if the particular dry dock is capable of accommodating the unequal weights. The use of fiberglass or composite materials can mitigate this consideration by reducing the over weight. Figure 20 shows a concept, also used by CMR, of sectionalizing the enclosure. This deployment scheme can accommodate crane access without compressing the entire system to create an opening and spreads the weight of the enclosure more equally over the length of the dry dock. The more sections the more convenient it becomes to provide openings for crane access.

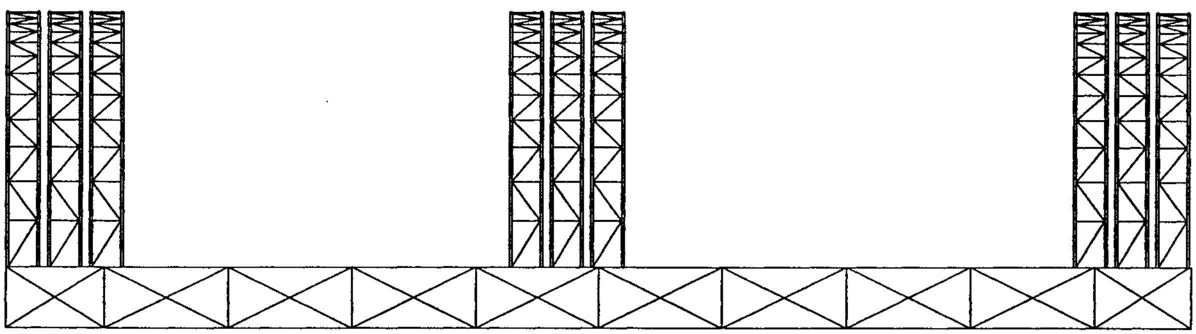

Figure 20: Sectionalized Horizontal Deployment

Attempts to provide enclosure for the largest vessel in a dry dock's potential service fleet will generally require a very large enclosure. Further, a ship with unusual or special structures that exceed the clearance limits of the now oversize enclosure will undoubtedly arrive shortly after the enclosure is complete.

Because the cost and complexity of sizing enclosure for the unknown will vex owners and designers alike, it is worth the effort to evaluate concepts that:

- can work for most of a particular service fleet
- Be relatively easy to retract to provide unlimited clearance.

The enclosure concept illustrated in Figure 21 provides this capability.

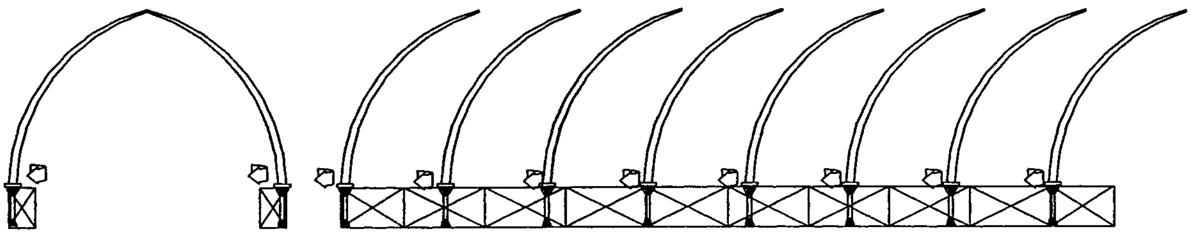

Figure 21: Rotating Cantilevered Arches

In this concept, the arches rotate 90 degrees providing complete removal of overhead interferences. It is in this application that the high strength of composite materials may play a very useful role. The mechanics of rotation will require some imagination, but then a cable could attach at the peak and act as a lanyard to pull the masts into the open or closed position. The foundation could be constructed using a pin and sleeve concept as shown below.

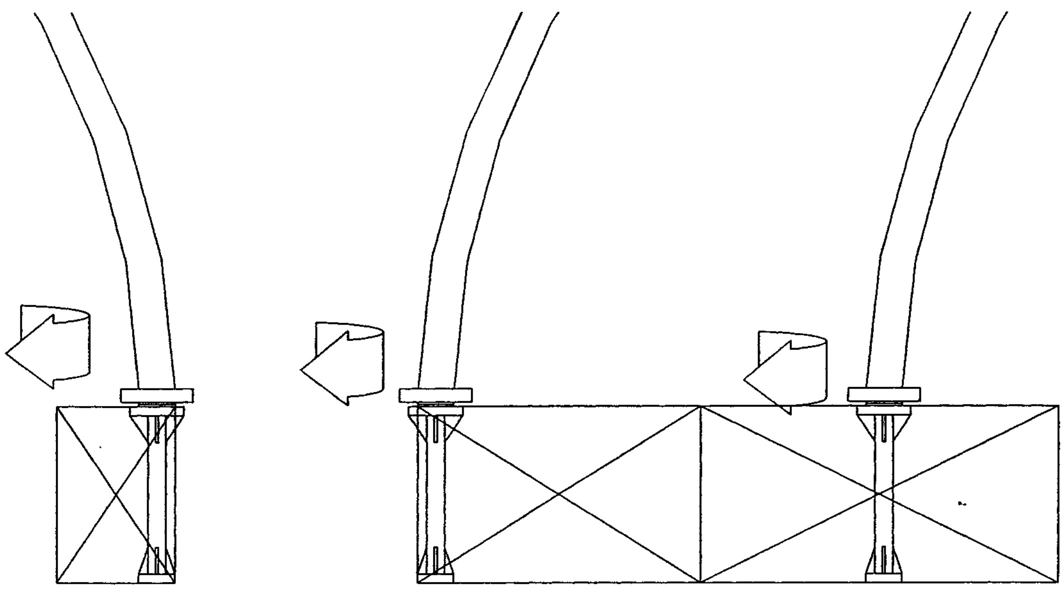

Figure 21: Rotating Boom Pockets Built into Wing Wall

The rotating beam pockets could also be constructed on the inside, outside or on top of the existing wing wall. By building up from the wing wall, the overall length of the boom can be reduced.

Another concept that will, no doubt require composite materials is the flexible mast as illustrated in Figure 22.

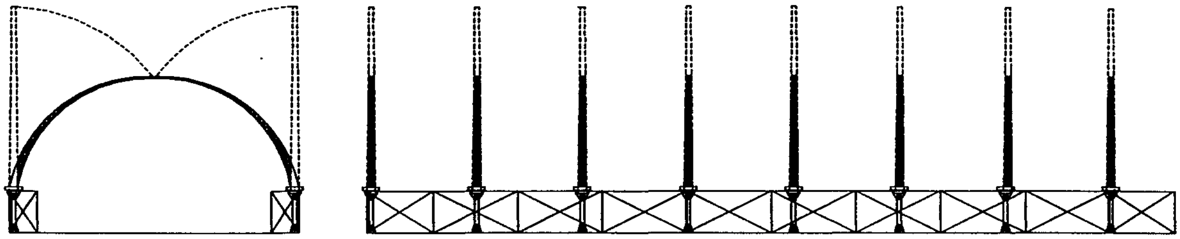

Figure 22: Flexible Mast

Flexible masts could be asymmetrically shaped to provide the appropriate directional stiffness and flexibility needed to resist lateral forces from the tension membrane and provide sufficient flexibility to be tensioned into the required shapes. The varying geometry along the length could be accomplished by adding thickness to the tube walls or adding layers of tubes as required. Lateral stiffness needed to resist prestress and live loads acting on the membrane could be provided by using an ellipse shaped tube as shown in Figure 23.

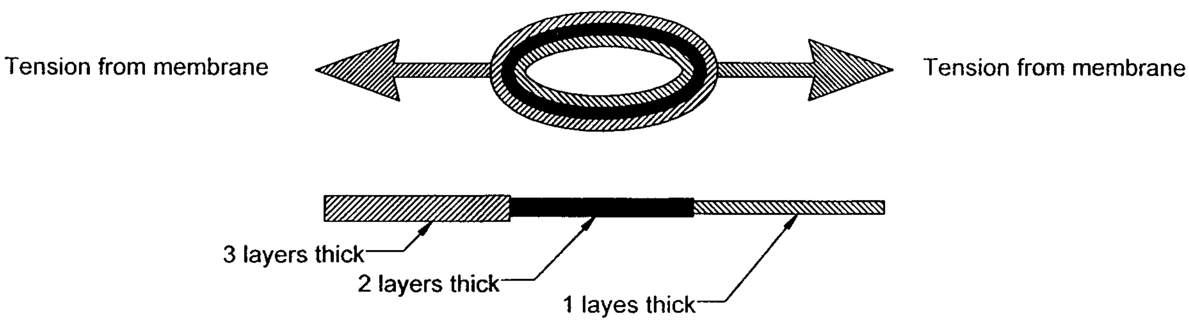

Figure 23: Cross-Section and Elevation View of a Flexible Mast

Figure 24, below, describes a section for a flexible boom developed by George Ward & Associates[8] that could be drawn from pultruded fiberglass or other composite material. Notice the pair of open channels on each side of the boom section. These channels are intended to function like a sail on a sailboat for raising and lowering sails, or in this case, membrane panels of the enclosure. Directional stiffening and flexibility is developed in the shape and wall thickness of the section. Varying the wall thickness along the length of the boom could provide differential stiffness to provide a parabolic shape when tensioned into the closed position.

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[8] George Ward, George D. Ward & Associates, 4941 S.W. 26th Drive, Portland OR, 97201, Telephone (503) 293-6075

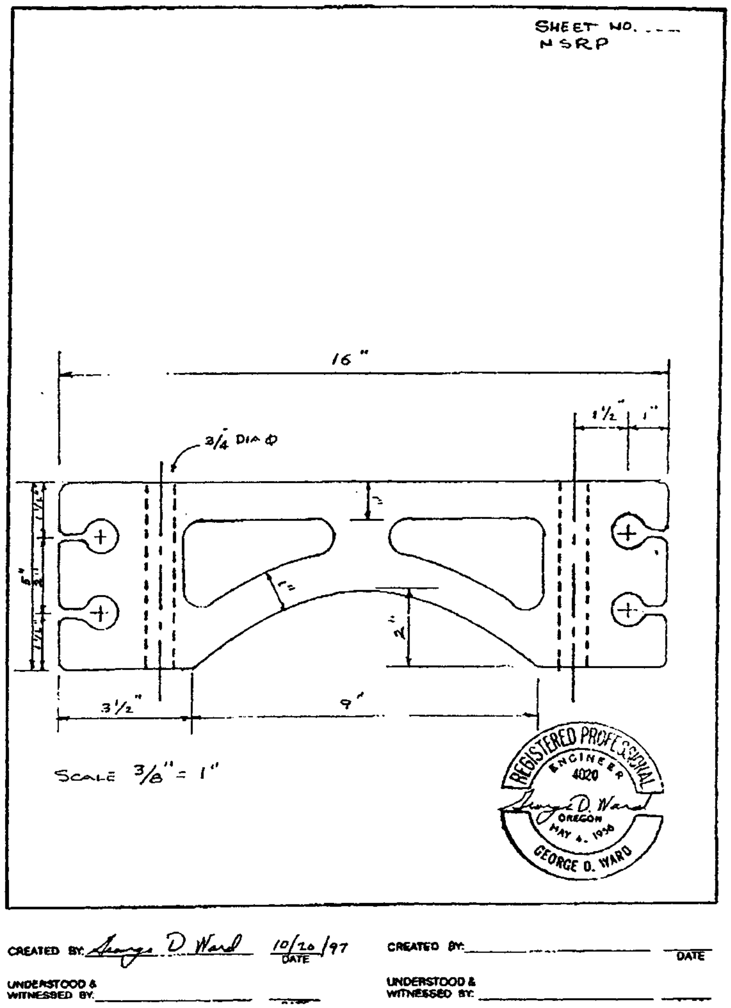

Figure 24: A Pultruded Boom Section with Sail Channels

The following discussion is about the operating requirements of a flexible mast system mounted on a floating dry dock.

The selection of a structural system that will meet the unique requirements of a tension fabric enclosure over a dry dock dictates that all the primary structural components must be capable of meeting the following specific operational requirements.

1. All major roof beams or flexible masts, including the covering material, must be retractable along the centerline of the dry dock in order to provide clearance for the safe passage of rigging, masts, superstructure and funnels of a vessel during docking and undocking. Upon their being closed over the vessel, tension will be applied to both halves by transverse cables resulting in the post-tensioning of the roofs structural members.

2. When the space requirements of vessels while in dry dock is too great to permit total closure of both halves of the deployable roof system cables are to be attached to the outer ends of opposing roof beams and sufficient tension applied to resist the upward reaction of negative wind pressures between the two halves even though the roof remains partially open.
3. When the cable tension is released between the ends of opposing roof beams each beam will have sufficient elasticity to enable it to spring back in the direction of the inner face of the wing wall until it is straight and in a vertical or near vertical position. While in the vertical or near vertical position each beam, now functioning as a mast, shall be stiff enough to be self-supporting without the need for post-tensioning except when wind velocities require that post-tensioning be re-applied for safety purposes. Where ship repair or maintenance requirements call for the enclosure of only one side of a vessel, the unused half of the retractable roof structure is to be capable of free standing in its fully open position to reduce deployment costs. For overhead crane access or other access requirements it will be possible to open individual roof panels at random without disrupting the overall structural integrity of other roof elements still in the closed position.
4. The material selected for use in fabrication of the spring beams must be resistant to corrosion, lightweight, strong but extremely flexible and capable of being fabricated in any lengths up to approximately 100 feet. It must also be fire resistant, easy to assemble and erect and also capable of receiving as well as releasing a round, polyester rope edge anchor formed into the edges of individual fabric roof panels.

A Flexible Composite Structural Frame

One form of structural components thought to be capable of meeting the requirements for a retractable frame system would be customized, composite reinforced fiberglass beams fabricated by the pultrusion process. This process utilizes a variety of plastic resin formulations reinforced by embedded glass, polyester or possibly carbon fibers. The pultrusion process is the outcome of research and development by STRONGWELL [9] formerly known as Morrison Molded Fiberglass Company (MMFG). Standard structural shapes fabricated by STRONGWELL using the pultrusion process are marketed under the name EXTREN. EXTREN's significant features applicable to flexible beams proposed for use in dry dock enclosures are:

1. Flexibility
2. High strength, on a pound for pound basis it is stronger than structural steel
3. Lightweight – weighs 80% less than steel and 30% less than aluminum
4. Dimensionally stable

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[9] Strongwell, 400 Commonwealth Ave., Bristol, VA 24203 Phone: (540) 645-8000 Website: www.strongwell.

5. Corrosion resistant, impervious to a wide range of corrosive environments
6. Available in any lengths, over 100 feet if required
7. Easy to work and erect (carpentry tools)
8. Durable in extreme weather conditions
9. Can be painted for extended durability
10. Flame retardant
11. Dimensional stability – the coefficient of thermal expansion of is slightly less than steel and significantly less than aluminum.
12. Anisotropric – like the woven fabric, this material is not homogeneous or isotropic, therefore, the mechanical properties are directional, a desirable characteristic for this proposal.
13. Effect of temperature – susceptible to degradation at extremely high temperatures but actually gets stronger in cold temperatures.

The strength of a composite fiberglass member is determined by the type, quantity, location, and orientation of fibers in the matrix. Corrosion resistance, flame retardance, impact and fatigue resistance, maximum operating temperature and strength are determined by the type of resin used to bind the fibers together. Pultrusion is the manufacturing process used in producing continuous lengths of reinforced plastic. In pultrusion, fibers are pulled through a wetting mechanism where the fibers are saturated in resin and then a heated die to produce structural shapes.

The use of the above trade names, processes and physical descriptions is not intended to imply that these are the only materials, processes or products being investigated for use in dry dock enclosures. Nevertheless, this project's principle investigators wish to thank STRONGWELL for providing technical support

Figure 25 below provides some comparisons of the lengths of various flexible booms, in the open position, to the resulting overhead clearance when the booms are closed.

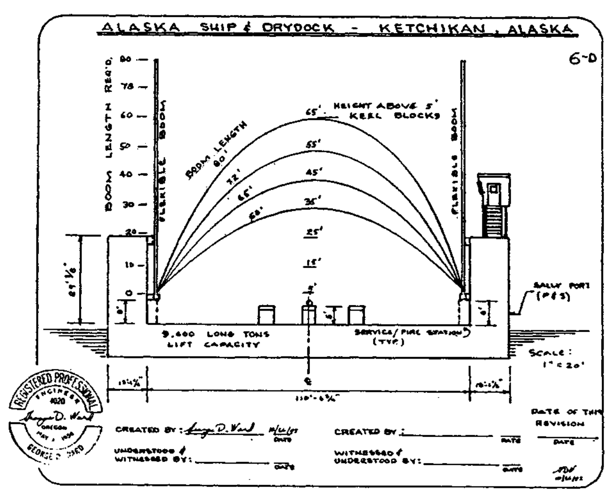

Figure 25: Flexible Booms - Relationship of Open to Closed Overhead Clearance

A simplification of the flexible boom concept is the use of inflexible booms. Figure 26 illustrates the relation ship of open boom height to closed overhead clearance for inflexible booms.

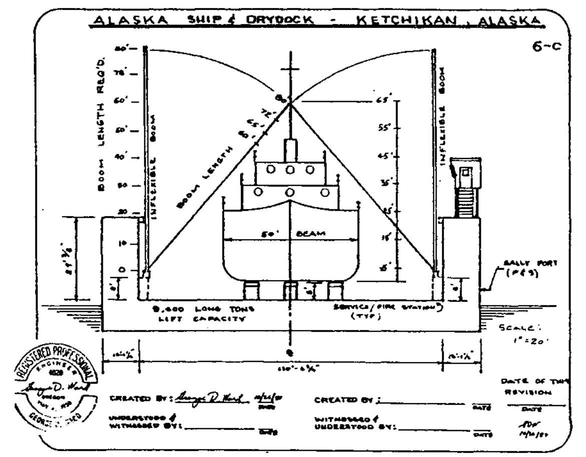

Figure 26: Inflexible Booms
Relationship to Open Boom Height to Closed Overhead Clearance

Inflexible booms may be useful if the enclosure is intended to extend only to the ship's main deck as illustrated earlier in Figure 3 on page 7.

Flexible or inflexible booms could also use horizontal movement. Adding this functionality will allow the booms to either compress for storage when not in use or, if capital funding is limited, function as a partial enclosure that can move the length of the vessel. Figures 27 and 28 show booms in the extended and retracted positions.

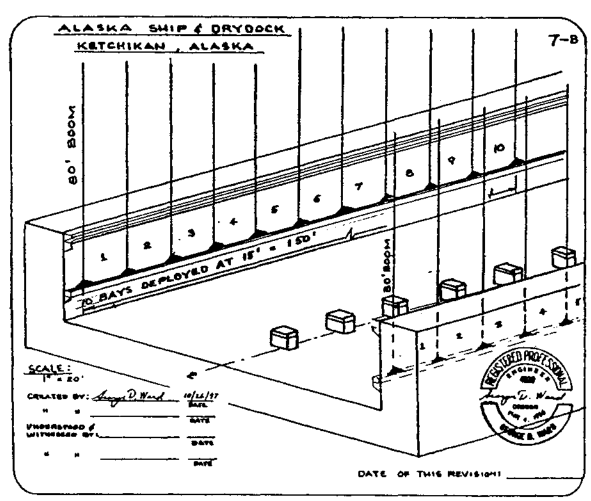

Figure 27: Booms in Extended Position

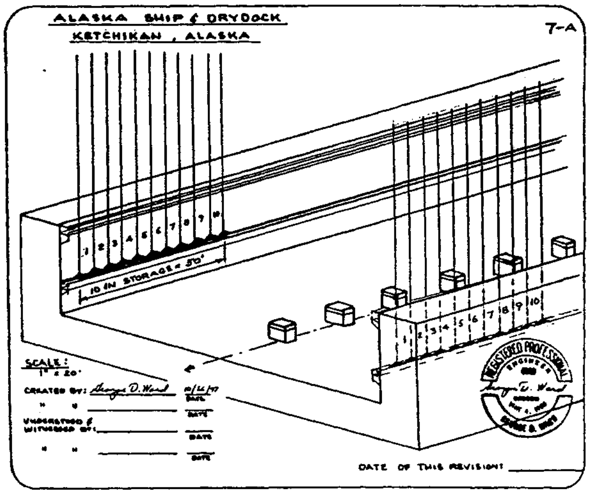

Figure 28: Booms in Retracted Position

Combining flexible and inflexible properties in the boom may also be useful in providing curvature needed for prestressing the membrane while developing strength in the lower section of the boom. Figure 29 presents a concept where the lower section of the boom is rigid and attached to the wing wall with an adjustable mechanism for raising or lower the boom. When the flexible boom is lowered to the desired position, the upper portion of the boom is tensioned in to final position providing curvature.

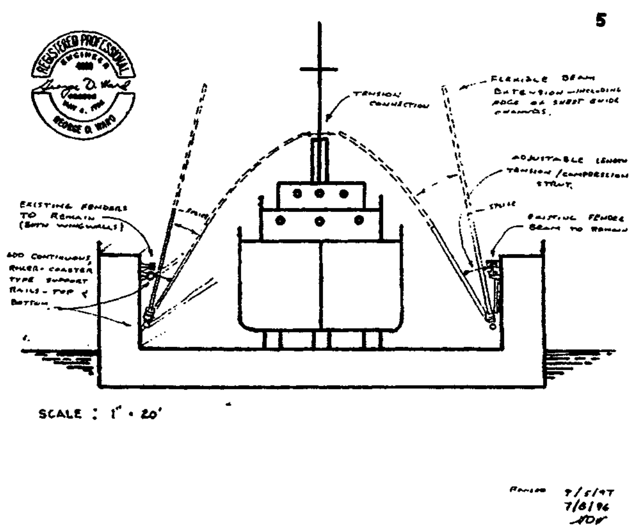

Figure 29
Combination Inflexible & Flexible Booms Cantilevered to Closed Position

Any boom arrangement suspended from the inside wing wall will be constrained in the amount of double curvature that can be introduced because of intrusion into the valuable production area of the main deck of the dry dock. Mounting the booms onto falsework on top of the wing walls will provide greater opportunity to provide double curvature. Figure 30 shows cantilevered booms mounted on wing wall false work. The note on the drawing pointing to "valley profile" indicates the relative scale of double curvature required in tensile membranes.

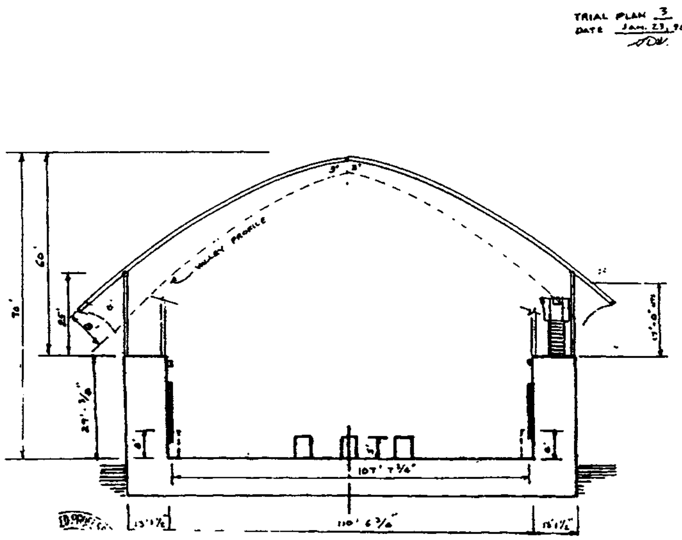

Figure 30

Cantilevered Booms Providing Double Curvature

Figure 31 clarifies Figure 28 and what is meant by "valley profile". The tensioning cable that pulls the valley or double curvature into the membrane forms the valley profile.

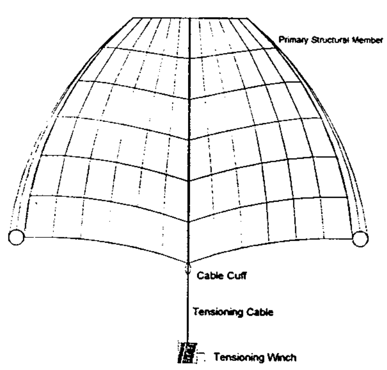

Figure 31: Double Curvature in a Tensile Membrane

The last structural concept to be introduced in is the idea of mounting the booms on sliding feet for vertical adjustment of the enclosure. Figure 32 provides an illustration of how this concept might work. Constructing falsework on the wing wall deck provides greater vertical adjustment and the top of falsework can provide space for mounting mechanical equipment needed to operate the enclosure system. The use of rotating or flexible booms in combination with vertically operating membrane systems gives this concept a wide spectrum of operational functionality.

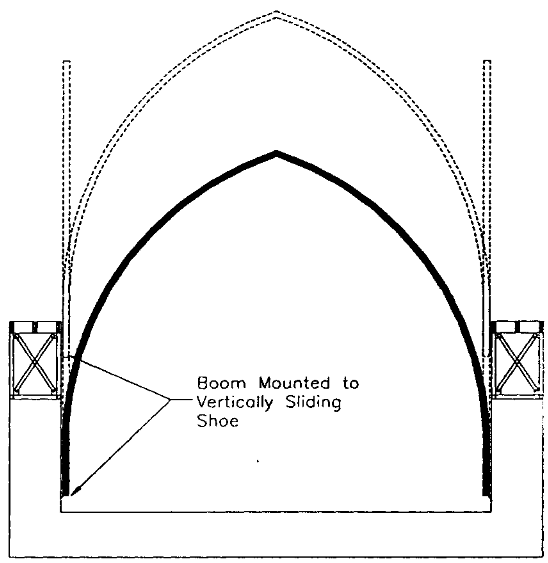

Figure 32: Vertically Sliding Booms

Summary of Structural Support Systems

The production demands of activities conducted in dry docks will require new ideas to provide additional flexibility and adaptability in traditional tensile design. Conventional tensile structures range from the fully configurable, as represented by temporary structures used by the coatings industry, to the least configurable as represented by large, permanent tensile structures used for large public spaces such as the Denver airport. The final design of a dry dock enclosure will provide the adaptability of temporary and portable systems with the cost effectiveness and scale of large, permanent tensile structures.

Considerations unique to the industrial activities occurring in dry docks suggests the proposed tensile structure should be permanently installed on the dry dock to satisfy ease of use yet be flexible enough to provide retractability for venting and access considerations. The ability to prestress and relax the frame as well as the membrane is a new concept and new methods for quickly and efficiently introducing and removing prestress must be devised.

Retractability typically comes at a heavy cost in traditional tensile structures. The Fukuoka Dome in Japan reportedly has dedicated 20% of the project cost to retraction. Typically, the effort to provide retractable elements overshadows the problem of enclosure itself. The proposed tensile structure for dry docks will require an innovative retraction system. Flexing and hinging of major frames will be used to provide large-scale retraction as may be necessary for docking high profile vessels..

Section 8 THE TENSION MEMBRANE

The purpose of this section is to identify and explore issues related to deployment of flexible membranes that will achieve cost-effective enclosure of ships in floating dry docks. The final selection criteria for a dry dock enclosure will be based on: a) purchase price; b) installation cost; c) operational costs; and d) maintenance costs of the enclosure system.

In the last twenty years, technical advances in materials and design have made tensile architecture a popular building form where aesthetic values are critical to the design goal. However, tensile buildings are still in their infancy. For example, technological innovation is needed to address the special requirements of various manufacturing industries such as ship building and ship repair. Tensile construction is a logical choice for enclosing ships in floating dry docks because large areas can be enclosed with minimal mass. Total enclosure of ships in a dry dock becomes problematic when envisioning a structure large enough to enclose the top-most antenna of the largest imaginable ship that may occupy a particular dock. For this reason, a dry dock enclosure must be conformable. That is, it is critical that the enclosure shape be adjustable. This is needed to accommodate different size ships and to accommodate frequent crane access to any part of the ship at any time

The information presented on page 28 characterizes the classes of enclosures for floating dry docks based on modes of operation. This section characterizes membranes based their behavior during deployment. Because tensile construction requires all of the building components to rely on each other to achieve stability, the details of each component become extremely important. The information presented in this report may not provide all of the answers that are needed to provide a useful dry dock enclosure, but it will identify those items that are needed to adapt fabric structures for use in industrial applications

Membrane Classification

As in the previous discussion of primary structural members, the type of deployment needed to operate the system will be used to classify the membrane enclosure. For example, the word "retraction" or "extension" of the enclosure can be used to classify the proposed dry dock enclosure concepts. For the membrane system, the complexity of classification is simplified because the primary support system will determine the basic operating principles of the overall enclosure. For membranes then, we have three principle classes of membrane

- Fixed
- Flexible
- Semi-Rigid

Fixed Membranes: For a fixed membrane, the flexible fabric remains in tension to retain its total surface area during all phases of deployment. Fixed membrane schemes will have minimal complications for edge control of the membrane but deployment will involve movement of relatively large structures or sectionalized panels.

Flexible Membranes: are characterized by a radical shape change as the membrane moves through its deployment cycle. In the closed position, the membrane is under tension and extended to its greatest dimension. In the open position, the membrane is relaxed and folded or rolled to a fraction of its surface area providing access to the interior of the enclosure system. Critical design issues for flexible membrane schemes include control of edge conditions throughout the deployment cycle and mechanisms capable of efficiently applying or removing pretension in the membrane.

Semi-rigid Membranes: These membranes retain their total surface area or boundary shape like a fixed membrane. Yet, a semi-rigid membrane is capable of flexing in one direction during deployment. That is, they are able to conform to the curves established by the supporting structural elements. Fiberglass or composite panels are examples of semi-rigid membranes. Semi-rigid membranes are stiff and rely on this structural quality to resist flutter where a flexible membrane relies solely on pretension and double curvature to resist flutter. Semi-rigid membranes will most likely be useful in vertical deployment schemes where panels slide from a fully overlapped or nested position when open to a shingle position when closed.

Open & Closed: When an enclosure is open, the deployable panels are retracted to allow crane access or entry of oversize vessels. When an enclosure is closed, the panels are extended to form a complete enclosure. The open and closed relationship shall also refer to the condition of the membrane at its various stages of deployment; that is when a membrane is closed or extended, the enclosure is closed. When a membrane is open or retracted the enclosure is open.

Materials of Construction

The selection of the appropriate fabric for use in a tensile structure is particularly critical because the fabric, or membrane, itself transfers or carries pretension and applied loads to the supporting components of the structure. In some designs, failure of the fabric membrane may cause failure of the entire structure, a condition to be avoided in dry dock enclosure.

The Sourcebook printed by the Fabric Architecture Magazine provides an excellent discussion of the materials and techniques used in fabric structures. This section will summarize material presented in the 1997[10], 1998[11] and 1999[12] Fabric Architecture Sourcebooks.

Fabric structures come in three basic forms defined by the methods of achieving structural support; 1) air, 2) tent, and 3) tensile structures.

> 1) Air structures are most successful when used as low, wide buildings. The wind load will be minimized if the buildings are kept low and wide. The geometry of enclosure for floating dry docks is tall and narrow; a configuration that reduces the survivability of air supported structures. For this reason air supported structures have not been pursued in this study. This is not to dismiss air structure entirely. Pneumatic components may be used in some applications to apply pretension as will be discussed later or provide support for tensile structures ancillary to dry dock enclosure such as end walls or weather seals. The Pneumatic Hall 'Airtecture', described in the book Soft Shells[13] uses "pneumatic muscles" to tension a cubic interior. Innovations in tensile technology like 'Airtecture' may prove useful in dry dock enclosures.

> 2) Tents come in two basic configurations; pole-supported and pipe frame-supported. Pole-supported tents are made with the fabric tensioned over the poles and cables. Subsequently, the entire enclosure is supported by cables and or ropes. These cables or ropes are tied off to the foundation modern tents can span up to 120 feet in width. Another form of tent uses frames to support the fabric. The entire system is anchored to a foundation. Clearspan structures are similar to frame-supported tents, but trusses are used in place of frames for the supporting structure. The trusses allow greater span widths. Clearspan structures are generally more permanent than frame-tents. Some clear span tents have channels mounted to the trusses between which fabric panels are stretched. In this type of construction, tension in the fabric defines the shape of the panel yielding a tensile roof system

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[10] 1997 Architectural Fabric Sourcebook. Fabrics & Architecture, Industrial Fabrics Association International (IFAI). St. Paul. 1997.

[11] 1998 Architectural Fabric Sourcebook – Loads & Anchoring. Fabrics & Architecture, Industrial Fabrics Association International. St. Paul. 1998

[12] 1999 Architectural Fabric Sourcebook – Fabric Basics. Fabrics & Architecture, Industrial Fabrics Association International. St. Paul. 1999.

[13] Schock, Hans-Joachim. Soft Shells Design and Technology of Tensile Architecture. Birkhauser. Basel. 1997.

3) Tensile structures are identified by their curvilinear shapes. Hyperbolic paraboloids and hyperboloids are commonly used to create anticlastic curves forming the double curvature. The curvature of tensile structures is key to their structural integrity and provides resistance to applied loads of wind and snow.

Fabric Types

Fabrics used in tensile structures include four main groups; 1) films, 2) meshes, 3) laminates, and 4) coated fabrics.

Films - are transparent polymers extruded in sheet-form without a supporting substrate or scrim. They are inexpensive but lack the strength and durability to be of use in large architectural structures.

Meshes and Netting - are broad terms referring to any porous fabric with open spaces between its yarns. Meshes generally have larger spaces than netting and they can be knitted, woven, or extruded. Netting is a type of mesh, but usually has smaller holes and the yarns are knotted to create the material. Both mesh and netting may be useful in structures designed to reduce wind speed

Laminates and coated fabric - – when compared to meshes or films, coated fabrics are the most widely used membrane in tensile structures. Coated fabrics are used more often than films because: they have a high tensile strength; their resistance and protection to the weather is better; and their service life is longer than other types of fabric materials. Coated fabrics generally have longer service lives and better bonding capabilities than the laminates. The materials most widely for structural fabrics are:

- polyester, laminated or coated with polyvinyl chloride (PVC)
- woven fiberglass coated with polytetrafluoroethylene (PTFE) or silicone.

Vinyl (PVC) Coated polyester

Polyester fibers laminated or coated with PVC are the most common fabrics used in pre-engineered fabric structures and are being used increasingly in custom designed tensile structures. Polyester's strength, durability, cost, and resistance to stretch are all factors that have lead to its widespread use. The softer flexible polyester fibers will better accommodate the service requirements of enclosure schemes. This is because they can adapt better to bending and folding; a requirement needed to accommodate deployment in floating dry docks. PVC coated polyester also has sufficient strength and dimensional stability to be used as a *fixed membrane*.

Vinyl coated polyester has three structural components: 1) a polyester scrim, 2) a bonding or adhesive agent, and 3) an exterior PVC coating.

Polyester scrim is composed of high-tenacity, continuous filament yarns. These yarns provide dimensional stability and possess the ability to bend and fold without severely degrading tensile strength. The size and number of yarns per inch determines the fabric's tensile strength. A bigger yarn with more yarn per inch will increase the fabric tensile strength. Denier refers to the size of the yarn and is a measure of the number of yarns per inch giving an indication of the fabric's tensile strength. Fabrics used in temporary or smaller architectural applications typically weigh between 2.5 and 10 ounces per yard and have a tensile strength of between 300 and 650 pounds per inch. Fabrics weighing 18 to 28 ounces per yard are commonly employed in larger architectural structures requiring longer service life.

The adhesive agent bonds the PVC to the scrim and prevents wicking of moisture into the polyester scrim.

The PVC coating protects the polyester scrim. The PVC coating can contain chemicals to resist penetration of moisture, growth of fungus and mildew, increase fire retardancy, and reduce color fading. Polyester fibers, like fiberglass, melt rather than burn; however, polyester fabrics are not rated as noncombustible. Perhaps this is because a polyester fabric has a lower melting point.

Vinyl Laminated Polyesters

These fabrics are mostly used in low-tension applications such as awnings and tents. Laminates are two or more layers of PVC joined by heat, pressure and an adhesive around a polyester scrim. These fabrics see wide use in the enclosure industry where temporary enclosures are required for relatively short periods. Because of their lower cost, laminates are often employed in one-time use applications and in projects where containment is a line item cost for doing the job. An efficient and cost effective deployment scheme for shipyards will most likely use longer lasting fabrics for waste minimization and cost considerations.

Teflon (PTFE) Coated Fiberglass

This fabric is comprised of woven, continuous glass fibers coated with PTFE. This fabric has a high ultimate tensile strength and does not exhibit significant stress relaxation or creep. The PTFE coating is inert and immune to UV radiation. Because the glass fibers are brittle and subject to breaking this material will lose tensile strength if subjected to bending or folding. Teflon coated fiberglass is by far the most expensive fabric in wide spread use, but can survive nearly 20 to 25 years of service life in the proper application. The life expectancy may be reduced in an industrial application where the fabric is subjected to the abrasive action from sandblasting grit and stress related to opening or closing the panels; i.e. deployment. Because the glass fibers are relatively brittle, use of this fabric will most likely be limited to *fixed membrane* enclosure schemes where the fabric will retain its shape throughout the entire deployment cycle. This material is non-combustible and dimensionally stable. Fiberglass fabrics are the only fabric membranes that meet the U.S. model building code definition of noncombustible.

Silicone Coated Fiberglass

This fabric is composed of glass fibers coated with silicone and has different properties than Teflon coated fiberglass. It is lighter in weight, less expensive, does not have Teflon's reflective qualities or low heat absorption ratio.

Woven PTFE

This material is made of woven PTFE fibers. It is not widely available but does provide a fabric that is highly resistant to environmental factors and does not lose strength after repeated bending and folding. This flexibility may make a woven PTFE a useful fabric for flexible membrane structures. This material is more expensive and the strength is lower than glass or polyester. Thus, its usage may be limited in large structures.

Nylon

Nylon is stronger and more durable than polyester but its higher cost and ability to stretch makes it unsuitable for large structures.

Kevlar

Woven Kevlar is a lightweight and strong fabric but its high cost limits its use in large buildings.

Semi-Rigid Membranes

Fiberglass reinforced plastic (FRP) panels may be suitable membranes to bridge openings required for crane access. Syntechnics, Inc. offers a corrugated flat cover system that can bridge spans up to 35 feet in width with a 12-inch deep corrugation. The lengths of these panels are limited only by shipping and handling considerations. Panels widths up to 50 feet can be custom constructed with deeper corrugations. Actual weight and costs for these panels will be determined by the proposed spans and overall load considerations but for a 35 foot panel the weight ranges from 5 to 7 pounds per square foot and cost from $15 to $20 per square foot.

Fabric Properties

The manufacturing processes used in structural fabrics involve numerous variables that result in wide variations in physical properties of similar fabrics from different manufacturers. Because of this wide variation in product properties, physical test data and manufacturers characterization are the only reliable measures of relative quality from one competitive product to another.

Structural properties of fabrics are related to stress versus strain (unit load versus unit elongation), resistance to cold cracking, life expectancy or service life, and the mechanisms of joining the material using radio frequency and heat bonding, glue, stitching, or mechanical clamping strips. The properties of fabrics for which standard measures have been developed include:

- **Strip and grab tensile strengths** are basic indicators of relative strength.

- **Trapezoidal and tongue tear strength** gives an indication of a fabric's ability to withstand in-place failure by tearing. Tearing occurs when one yarn fails, as the result of local concentration of stress, thereby increasing stress on neighboring yarns leading to their failure.

- **Adhesion strength** measures the strength of the bond between coatings and base materials or between laminates. This measure is an indicator of how well a particular fabric will perform at its seams when it is welded or bonded into a fabricated panel.

- **Resistance to cold cracking** – a fabric's ability to resist cracking in cold temperatures is measured in the laboratory by bending a strip of fabric 180 degrees over a 1/8 inch mandrel at ever lowering temperatures until the coating or lamination cracks. According to Mr. Frank Bradenberg[14] of the Seaman Corporation has developed two classifications of PVC coated polyester fabric that resists cold cracking. The Seaman Corporation's standard cold crack resistant fabric is classed as LTC and resists cold cracking down to –40 degrees Fahrenheit. This is the last temperature before a cold crack will develop on the laboratory bench. Mr. Bradenberg's recommendation for field handling of the LTC fabric is at 20 degrees Fahrenheit. At 20 degrees, the fabric maintains its ability to be folded and bent without damage while still being highly workable. The company's LTA fabric is rated to resist cold cracking at minus 67 degrees Fahrenheit meaning it can be easily handled in the field at minus 10 degrees Fahrenheit.

  A fabric's ability to resist cold cracking then, is also a measure of workability in the field. For enclosure schemes calling for shape changes of the fabric membrane in cold weather or for ship mounted schemes that may need to be erected in cold weather, a fabric's resistance to cold cracking can be a useful measure.

[14] Telephone interview with Mr. Frank Brandenberg, Seaman Corporation, 1000 Venture Blvd., Wooster, OHIO 44691 Telephone: (330) 262-111. Website: www.seamancorp.com

- **Flame resistance or retardancy.** Flame resistant fabrics are not flame proof. Usually flame resistant fabrics have a layer of PVC coating or laminate treated with flame resistant chemicals. The base polyester fiber is untreated as may be other layers of PVC coating or laminate. A flame resistant fabric will not support combustion by itself unless a large source of ignition is present that will cause the untreated fibers and layers to heat enough to begin combustion.

  The 1999 Architectural Fabric Sourcebook discusses flame resistance.

  > *"Flame retardancy tests measure the self-extinguishing characteristic of a fabric when subjected to flame. The industry has developed AF-1 and AF-2 classifications for architectural fabrics. Both types must have a flame spread rating of 25 or less and provide at least a Class C roof covering. In addition, AF-1 fabrics must pass tests related to resistance to external fire exposure and interior flame spread. In certain temporary or non-building structures, fabrics that meet NFPA 701 (flame resistance), or classification, may suffice."*

  For a discussion of fire code, testing methods see discussion on Fire Codes on page 11.

- **Finished weight and base fabric weight** are usually based on ounces per square yard and are a gross indication of the materials strength and wear resistance.

- **Top coatings** – Uncoated PVC will attract and hold dirt. Top coatings on fabrics increase UV and chemical resistance and prevent the accumulation of dirt and the growth of mildew as well as enhancing the cleanability of a fabric. These coatings tend to erode with age so thicker solution coatings last longer, but too thick of a solution coating will crack when folded or bent.

  Commercially available topcoats include a liquid applied acrylic and polyvinylidene fluoride (PVDF) applied at thicknesses of between 0.1 and 0.7 millimeters.

  A widely used top coat for PVC coated fabric is Tedlar© developed by DuPont. Tedlar© is about a 0.9-millimeter film of polyvinyl fluoride (PVF) bonded to PVC-coated fabric and withstands weather-related erosion longer than other topcoats.

  Acrylic or PVF coated fabrics may be suitable materials for use in tensile tent enclosures for use in shipyards. These materials will be expected to experience a significant amount of wear due to the frequent deployment of the fabric structure. Permanently mounted large structures will most likely require a long service life. Thus, for this application, bonded PVF films are probably the better choice.

- **Other properties** that are more difficult to obtain but will provide a more complete understanding of how a fabric will perform in a specific application or use include:

  - **Shading coefficients, solar, optical, and thermal performance data**. The properties that make tensile construction attractive for dry dock enclosure like low mass and translucency are the very same qualities that make them susceptible to rapid temperature changes in response to external conditions.

    Just as the dynamics of load distribution in a tension membrane are difficult to calculate using static analysis, so is the thermodynamic analysis of large tensile structures. For large structures, computational fluid dynamic techniques will be required to predict the thermal balance of the entire tensile structure. Dry dock enclosures with large volume interiors should be evaluated for and designed to use passive environmental control wherever possible.

  - **Acoustical data** – Fabrics will provide reasonable absorption of low frequency noise but have poor absorption ability for middle and high frequency sound. Concert shells require acoustic control. Some coatings and double membrane systems can provide the needed degree of sound absorption for some applications. The needed acoustic control for an enclosed dry dock is no different than any other enclosed workspace. These issues may be accommodated by an acoustic engineer at design time.

  - **Dimensional stability** is a measure of a fabric's ability..to resist creep or stretching over time and through varying ranges of temperature and tension.

  - **Cleanability** can be controlled by the smoothness of the surface and the introduction of fungicides to prevent the growth of molds and funguses.

  - **Seam strength** and stability is a measure of a fabric's ability to bond to itself.

  - **Construction method** – refers to handling limitations during construction of the enclosure systems. Limitations include the ability of the fabric to accept foot traffic or folding during construction. The question to be asked is; what are the handling limitations for the fabric, as they will be impacted by construction or operation of the enclosure?

- **General handling ability** is related to abrasion resistance and foldability.

In reviewing the properties of architectural fabrics, it is easy to see that selection of the correct fabric for any particular application depends on a number of design factors that will be determined by the basic design strategy of the enclosure. In addition to the obvious environmental factors, the tensile designer must determine how pretension will be addressed, what is the allowable creep and dimensional distortion, what thermodynamic changes can be tolerated in the system and, if the structure is retractable, what is the method of retraction.

Today most tensile structures are constructed using two different types of fabric; PVC coated polyester and Teflon coated fiberglass.

Teflon coated fiberglass has become the primary choice of fabric for permanent installations. The following list characterizes the pros and cons of Teflon coated fiberglass.

Pros:

Both components are chemically inert

Non-combustible

Easy to keep clean

Dimensionally stable

High tensile strength

Durable, 20 to 25 years life

Cons:

High initial cost

Brittle fibers cannot be folded

Difficult to handle because of stiffness

Fiberglass requires moisture protection coatings

Highly non-linear behavior at low stresses

Special seaming techniques required

PVC-coated polyester fabrics find wide use in lower cost, pre-engineered structures and are particularly suited for structures that must be portable or foldable. The following list provides a comparison of pro and cons for use of this fabric in a dry dock enclosure.

Pros:

Low initial purchase cost

Flexible softer fibers can tolerate bending and folding

Easy seaming

Affordable enough to be replace every 10 to 15 years

Cons:

Susceptible to UV radiation without protection

Medium tear resistance	Medium construction stretch

For the design of tensile structures, fabrics with strip tensile strengths between 500 and 600 pli are sufficient. These values can be applied to both fiberglass and polyester reinforced fabrics since they both experience losses of strength but from different mechanisms. Fiberglass is subject to weakening from handling during shipping and construction due to breakage of the brittle fibers. Polyester looses strength because of age and exposure to ultraviolet radiation. There is a notable difference in the ultimate failure of these two materials however. Fiberglass fabrics fail abruptly upon reaching the limits of their tensile strength as opposed to the softer polyester fabrics, which will reach a yield point where they will stretch extensively prior to breaking. Polyester fabrics may be safer in use because this extensive stretching would lead to the replacement of polyester fabrics before failure by breaking.

Fabric Costs

Mr. Steve Denbow[15] with Taconic Industrial Fabrics Division provided some general cost ranges for several types of widely used architectural fabrics.

PVC Coated Polyester.. $1.50 - $2.00 / sq.ft.

Silicone Coated Fiberglass.................................. $2.50 - $4.00 / sq.ft.

PTFE (Teflon) Coated Fiberglass .... $4.50 – $7.00 / sq.ft.

These are costs for the fabric only. Fabrication costs will add to the installed costs and will be determined by the complexity of the panel specifications such as edge treatments and connecting hardware.

A comprehensive listing of fabric manufacturers and fabric properties is available in the Fabric Architecture magazine's 2000 Designers Guide published by the Industrial Fabric Association International (IFAI)[16]. The IFAI is a non-profit trade organization dedicated to promoting the use of industrial fabrics. The IFAI bookstore has a number of excellent references describing tensile structures and their use in various applications around the world.

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[15] Telephone interview with Mr. Steve Denbow[15],Taconic Industrial Fabrics Division, 2475 Norhtwinds PKWY, STE 200, telephone (770) 640-7829. Email: steved@4taconic.com. Website: www.4taconic.com

[16] Industrial Fabric Association International (IFAI)1801 County road B W, Roseville, MN 55113, Telephone (800) 225-4324, Website: www/ifai.com

Fire Resistance & Fire Codes

Fire Resistance

Tensile fabric structures are inherently less prone to fire damage than conventional structures. Demonstrations have shown that fabric seams will open up and exhaust smoke and heat long before the fabric, cables and frames are damaged. A hole in the fabric surface is the most likely damage a fabric structure would sustain since most fabrics in use today are either fire resistant or at a minimum are highly resistant to flame spread.

Fire Codes

This section is a summary of an article[17] written by Mr. Richard N. Seaman, President of the Seaman Corporation.

Code agencies are concerned with how a particular building material performs in actual fire situations. Their concerns are directed towards the impacts of fire on both people who may be occupying the structure during a fire as well as the impacts on fire fighting personnel who attempt to extinguish the fire.

Four primary tests have been referred to by various code agencies. Mr. Seaman provides a concise summary of the tests

1. *NFPA – 701, "Flame-Resistant Textiles, Films". Counterparts to this test include Underwriters laboratory No. 214, Federal Standard Method 5903, and the California State Fire Marshal's Test.*

   This test method requires that a 10-inch by 2¾-inch sample of the membrane fabric be clamped in a fire test chamber and held in a vertical position. A Bunsen burner is then applied to the vertical sample and held there for twelve seconds. When the burner is removed, the fabric must self-extinguish within two seconds to pass the test. This method evaluates the flammability of a membrane fabric in the vertical position as would exist for the wall areas of a building.

   The NFPA-701 also incorporates a weather condition to determine if weathering effects on the fabric changes its fire resistance capabilities.

   This test has the longest history in defining approved fabric membranes for architectural fabric structures.

2. *ASTM E 84, "Standard Test method for Surface Burning Characteristics of Building Materials", a horizontal tunnel test.*

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[17] Seaman, Richard N. "Fire Performance History of Flame-Retardant Membrane Structures." Building Standards January February, 1984: 13-17.

This test requires that a 25-foot section of the membrane fabric be placed in a large horizontal tunnel. One end of the sample is exposed to a 4-foot flame for ten minutes. This measures two parameters, the flame-spread rating of the material and the smoke developed during the ten-minute fire exposure. The comparative standard for both of these parameters is asbestos cement board and red oak flooring, with asbestos board valued at 0 and red oak flooring valued at 100. This method evaluates the flammability of a membrane fabric on the underside when in the horizontal position. This will simulate a roof area.

3. *ASTM E 108, "Standard Test Methods of Fire Tests of Roof Coverings".*

   This test consists of three separate tests – 1) The spread flame test exposing the specimen to a large wind blown flame to see if fire will spread across the surface. 2) The intermittent flame test exposes the sample to three cycles of wind blown flame. 3) The burning brand test, which places a burning, crib on top of the sample to see if fire will penetrate the sample.

4. *ASTM E 136, "Standard Test Method for Behavior of Materials in A Vertical Tube Furnace at 750 degrees C.*

   A 1½-inch cube of the material is heated to 1,382 degrees F. This test attempts to evaluate whether the material will contribute fuel to a fire or whether it will physically survive a fire. For fabrics used in structures only the base material is tested, not the entire composite material. If the base material coating is less that 1/8 inch thick on each side and that coating or film can achieve a flame spread rating of less that 50 when tested to ATME 84, the material composite is then classified as a noncombustible material.

Most codes recognize NFPA-701 as defining a fabric as flame retardant and test method ASTM E 136 as defining a fabric as noncombustible. At the writing of this article, there had been no work done to determine if a noncombustible fabric performed any differently than a fire-retardant material.

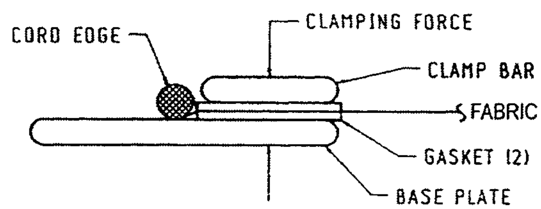
Mr. Seaman points out that the validity of a test method can be demonstrated by reviewing case histories. He cites several actual fires and notes that fires in fabric structures complying with NFPA-701 demonstrated several characteristics. The fabric did not continue to burn or support combustion. The area directly around the fire immediately melted through to the atmosphere venting smoke and fumes and dissipating heat as well as providing excellent access to fire fighters. Structural members were not damaged and the buildings were repaired in a matter of a few days.

Mr. Seaman concludes that structures built of fabrics that meet the NFPA-701 test as flame retardant are safe.

Edge Control of Membranes

Edge control for a fixed membrane is relatively well understood by today's tensile building designers. Edge control is the critical component that assures uniform transmission of tensile forces from the membrane to the primary structure. With out proper edge control, stress is likely to be concentrated in localized areas of the membrane. This can result in flutter, which is caused by concentrated load acting on a small area of the membrane. This condition often leads to failure of the membrane.

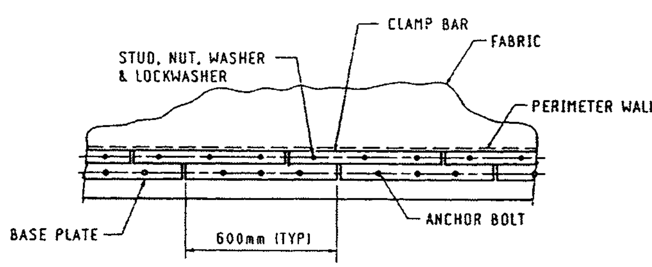
Figures 1 - 4 and 6 – 9 are reproduced here with the permission of the American Society of Civil Engineers[18]. The illustrations show typical edge terminations schemes commonly used in modern tensile structures.



Typical Clamping

Figure 1: Typical Clamping

Figure 1 illustrates a typical clamping scheme that provides positive and uniform edge retention using bar clamps and a cord edge. The cord edge, commonly called a boltrope, is bonded into the edge of the membrane to assure positive edge retention. Use of a single clamping bar may allow forces to be concentrated at breaks or joints in the bar. Figure 2 uses a double row of clamping bars with offset joints to provide full uniformity of edge control.



Perimeter Plan

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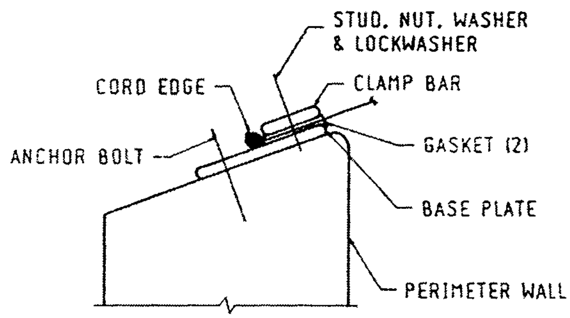
[18] Shaeffer, R.E. Ed. Tensioned Fabric Structures, A Practical Introduction. American Society of Civil Engineer's (ASCE)

Figure2: Double Bar Clamps

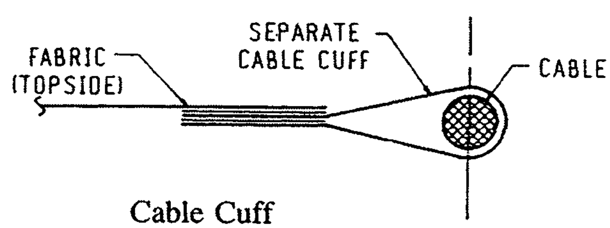
Figure 3 shows the bar clamp assembly anchored to a perimeter section. For dry dock enclosures, the perimeter section may take the form of a truss section or a tubular frame. These structural sections would be part of the structural framing system.



Perimeter Section

Figure 3: Bar Clamps Anchored to Perimeter Wall

Figure 4 illustrates edge termination where a cable or rope is sewn into a cuff. The cable accepts the uniform stress from the membrane and carries this energy to the cable ends that are terminated at the primary structural system. This type of flexible edge control often results in the familiar scalloped edges of many tensile systems. A modification of the cable cuff creates a bolt rope assembly which slides into an extruded section much like a sail and mast assembly. Figure 4 shows a typical cable cuff that provides excellent edge control for fabric membranes.



Cable Cuff

Figure 4: Cable Cuff

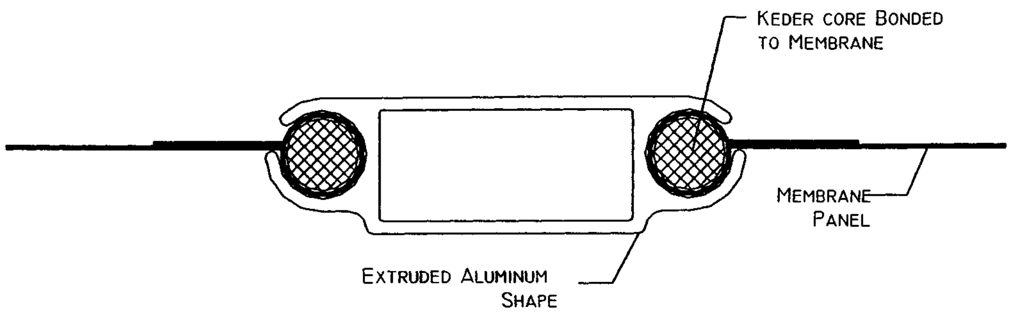


Figure 5: Bolt Rope or Keder Terminating in an Extruded Channel
Drawing by ASD

The assembly shown in Figure 5 can also be constructed using an edge treatment known as a Keder manufactured by the Franz Miederhoff OHG [19] and distributed in North America by the Munro Fastening & Textiles[20]. The Keder edge consists of a polystyrene core wrapped in a ballistic fabric cuff forming a tongue of about 2 inches. The tongue can be bonded to the edge of PVC coated fabrics. In the U.S. it appears that the higher cost of Keder has caused manufactures of temporary enclosure systems to adopt the less expensive bolt rope assembly. These enclosures are being manufactured for the general coatings industry and are often supported by scaffolding. For use in shipyards, where re-use of the membrane will be desirable, the ballistic fabric used in Keder may prove more durable in the presence of blast grit.

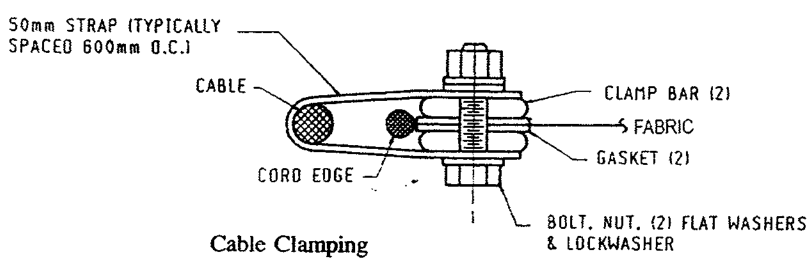


Figure 6: Cable Clamp

Figure 6 shows a cable clamp system that would be useful in deploying flexible membranes. The 50-mm strap could be replaced with a pulley that would travel along the cable during deployment of the flexible membrane. Development of a flexible clamping bar would be required to roll the fabric in its stored or open position.

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[19] Franz Miederhoff OHG. Websitewww.miederhoff.com.

[20] David Slorach, Munro Fastening & Textiles, 1334 Skyway Avenue, Etobicoke, Ontario M9W 4Y9, Telephone (416) 675-1102

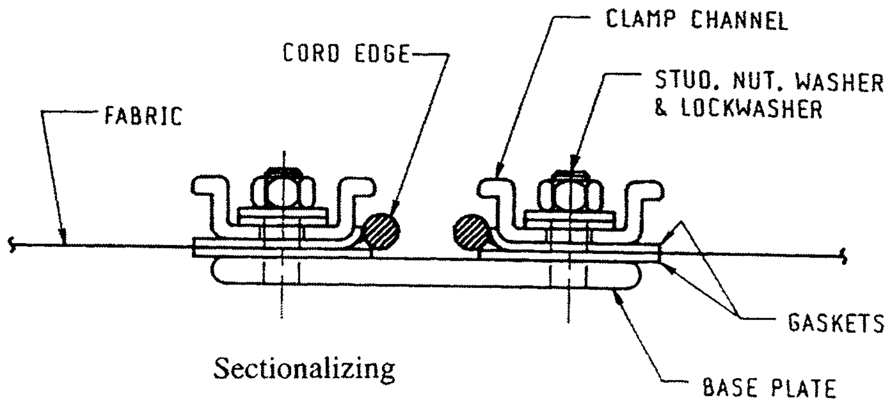


Figure 7[1]: Joint for Sectionalizing a Membrane

The efficiency of a tensile structure can be measured by its ability to reduce primary structural components with ever-larger membrane panels. Increasing the surface area of the membrane panels increases the total applied load, which increases the tensile forces that must be transferred from the membrane to the support structure. Figures 5 and 7 illustrate methods to join panel sections to form larger membranes in a technique call "sectionalizing". Figure 7 is a common edge treatment for large fixed membrane panels and Figure 5, using the Keder and channel, is useful with sectionalized, flexible membranes.

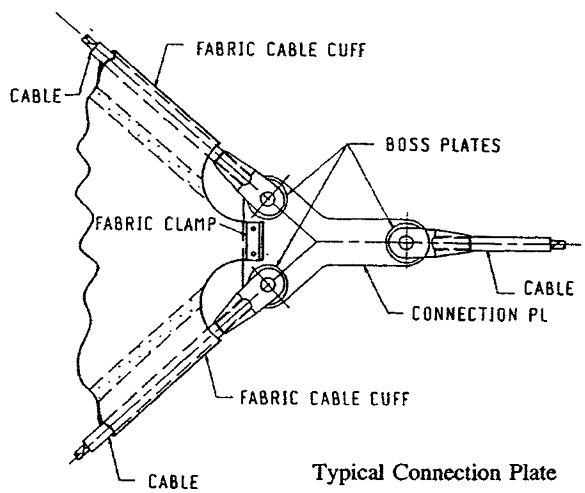
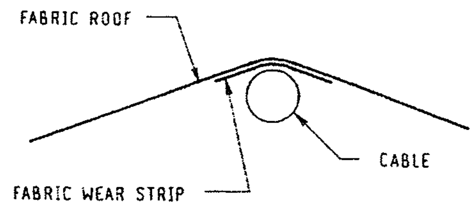
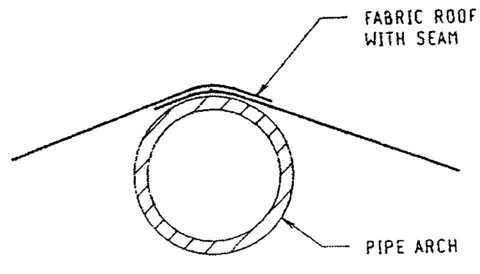


Figure 8: Corner Terminations

Corner terminations of membrane panels are critical areas for edge control. Membrane corners are areas where forces can be non-uniform and result in failure of the membrane. Figure 8 shows the robust fittings detail required to avoid point loads from occurring in the membrane corners.



Cable under Fabric



Pipe Arch with Fabric

Figure 9: Structural Support

In some deployment schemes, the membrane may require support by components of the primary structure or a cable. Figure 9 serves as a reminder of the importance of protecting the membrane with extra layers of material where it is in contact with structural frame supports.

Section 9 Deploying Tensions Fabric Membranes on Dry Docks

Deployment Considerations

The deployment of flexible membranes is relatively straightforward for small, tension fabric panels and is employed commonly aboard sailing vessel of all sizes. Deployment of large panels, as may be required for dry dock enclosure, becomes more problematic particularly when trying to minimize time and man power costs. Since the goal in using tension membranes is to reduce the overall weight and cost of the proposed structure the most efficient design maximizes the size of tensile panels in order to minimize the number primary structural components. Larger membrane panels will increase friction and energy in the deployment system and so a robust but efficient system for deployment of large fabric panels must be devised. Where it is beyond the scope of this project to provide detailed design of the mechanical systems used to deploy large tensile panels a short discussion of concepts will be provided to suggest avenues to acceptable solutions.

Existing Technology - Roll up Doors

Fabric membranes are successfully used to construct large roll up door assemblies to provide enclosure of vertical openings as might be found in aircraft hanger buildings.

Para-Port Doors[21]uses a patented roll up system. Electric motors impart torque to a cylindrical roll, which winds its way up a membrane to open the door. Initial discussions with Para-Port staff revealed that the system requires a vertical opening to work effectively and that the single membrane will not tolerate a significant amount of live load. Yet, this system deserves mention as it may suggest new strategies for deployment of large membranes over an arched configuration. There are two principle drawbacks to this system for use in arched dry dock enclosure systems. These are; 1) the system is unable to tolerate multi-directional tension loads; and 2) it is difficult to attain weather tight seals along the edges of the membrane in non-vertical installations.

Megadoor, Inc.[22] provides another patented system that does provide resistance to lateral loads. In this scheme, the door glides vertically in weather tight channels. A heavy horizontal beam located at the bottom of the door tensions the fabric panels. Lighter, intermediate beams carry wind loads to the edges and are used to transfer load to the vertical channels attached to the structural frames. Varying the size and spacing of the intermediate panels can accommodate high wind loads

Again, the manufacturer has not designed this system for vertical retraction, but it may suggest other methods for providing deployment of membranes between fixed structural members. According to company official's costs for Megadoor installations range around $50 to $60 per square foot and weigh 4 to 5 lbs. per square foot. Modifications to the MEGADOOR system would include introducing a return mechanism to replace gravity for use in sloped or arched configurations and provide for robust wearing surfaces in the edge channels. Figure 10 illustrates the large openings MEGADOOR is able to span and a view of the operation components.

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[21] Para-Port Doors, 1801 Sandusky St., Fostoria, OH 44830 (419) 435-7676

[22] Megadoor, Inc., P.O. Box 2957, Peachtree City, GA 30269 Telephone: (770) 631-2600,

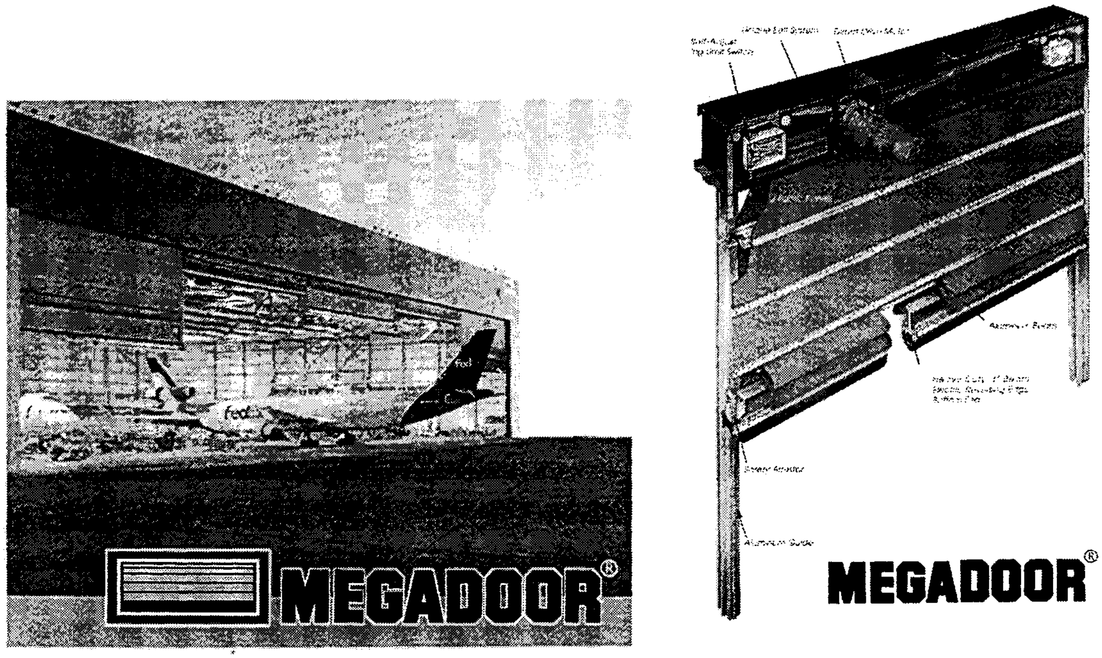


Figure 10: MEGADOOR Technology

Vertical Nesting Systems

Figure 11 graphically depicts a vertically acting deployment scheme where large, fixed membrane, fabric panels would ride on tracks or rails mounted to the arched support trusses.

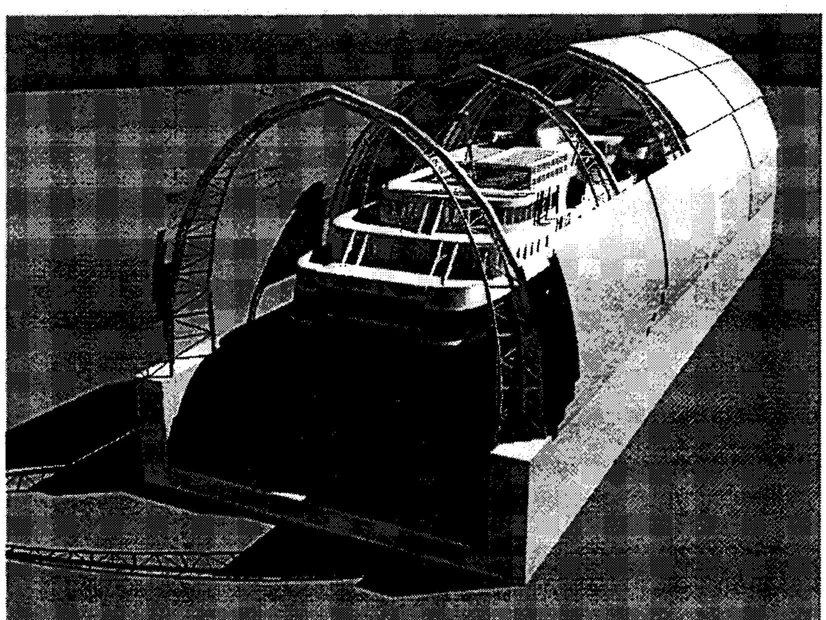


Figure 11

For fixed membranes of this size, a low friction deployment scheme will be required. Consider how a modern roller coaster is designed. These concepts suggest that a rail mounted deployment system is capable of transferring forces that are generated by large building panels and resisting alternating uplift and compression loads. Envision the fun loving passengers in Figure 12 below as representing the membrane surface.

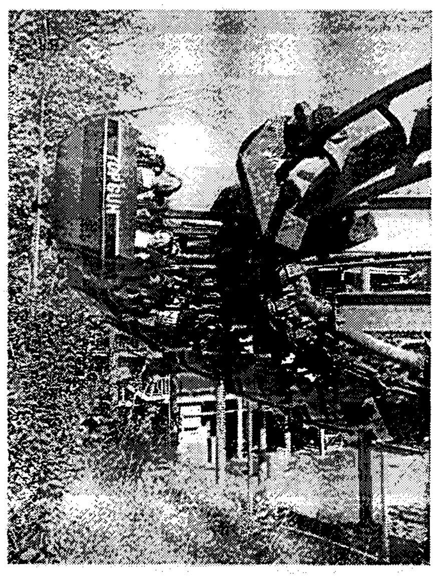


Figure 12

Rolling or wheeled mechanisms for deploying large fabric panels must be able to accept flexing and movement as is characteristic of tension structures. The roller coaster example, above, achieves flexibility with a hinged connection to the truck. The truck rides on wheels mounted to a pair of tube rails. The wheels are arranged to resist tensile forces transmitted through the hinged connection from the passenger cars.

Another less complex example of a roller system capable accepting varying directions in tension is illustrated by the conveyor system used in many dry cleaning establishments and shown in figure 13.

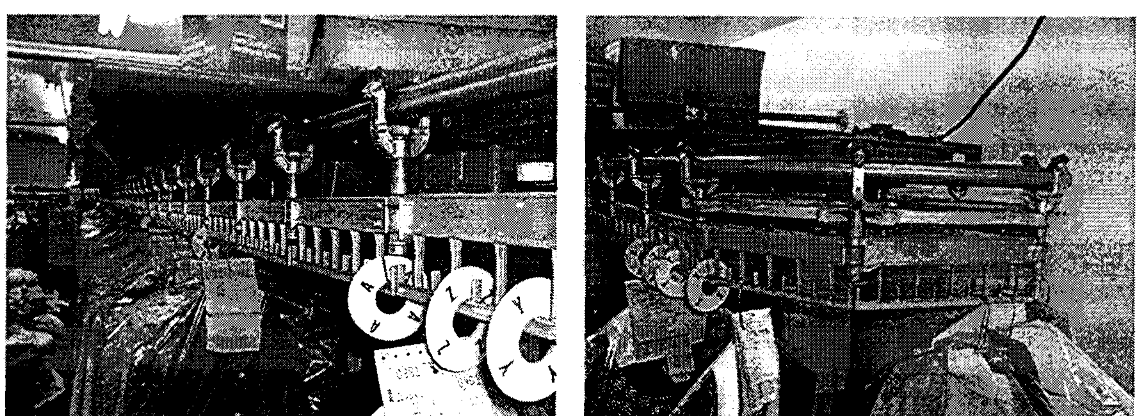
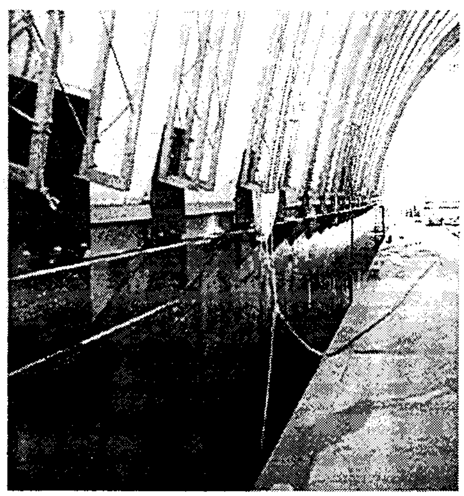


Figure 13

In this example, a single pipe supports a roller assembly with two wheels accepting the tension loads that would be transmitted from the membrane. The wheels are free to rotate about the tube rail to accommodate varying directions of tension. A third roller is located at the bottom of the yoke and would be useful in maintaining position of the roller yoke during deployment when pretension is removed. The right hand picture shows the roller yokes attached to a rigid bar that is hinged to accommodate travel around the curve. In a vertically deployed enclosure, system this rigid bar could represent the clamping bars of the tension frame and define the size of folds required to store the membrane in its retracted or open position.

Horizontal Deployment

Horizontal deployment of *fixed* membranes appears to be straightforward. For example, rail mounted building sections can be nested so those openings are available for crane access and clearance when is needed for oversize vessels. Horizontal deployment of *flexible* membranes is another matter. CMR Environmental Energy Research & Development Inc.[23] have accomplished deployment of flexible membranes for smaller floating dry docks using their proprietary enclosure system. Figure 14 shows the CMR system mounted to a floating dry dock, which mainly services repairs.



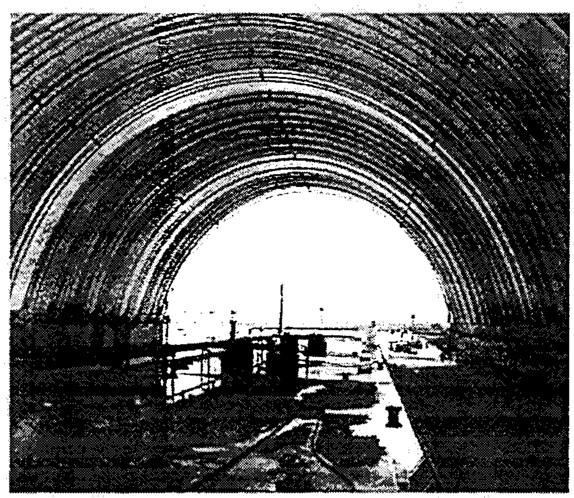


Figure 14
CMR Enclosure showing truss system on the left and sliding shoe assemblies on the right. Photos by permission of Brian Peterson[24]

[23] Mr. Rob Faber. CMR Environmental Energy Research & Development Inc. 31 Armstrong Ave., Ontario, Canada, L7G 4S1, Telephone (905) 873-4140

[24] Peterson, Brian. NSRP SP-1 Project 1-96-8: Open Area Painting Overspray Containment, Bremerton. 1999.

SEMI-RIGID RFP MEMBRANES

Reinforced fiberglass panels (RFP) are semi-rigid membranes and have properties that may be useful for enclosing ships on floating dry docks. The molded corrugations in RFP panels make them very effective in resisting both wind and snow load yet is flexible enough to conform to the curved shape of a tensile structure. These panels act as a one way plate, flexible in one plane and rigid in the other. Figure 15 below shows a typical Syntechnics, Inc.[25] RFP panel. According to Mr. David Schoate of Syntechnics, Inc. the largest standard panel is 30 feet in width with a 12-inch deep corrugation weighing between 5 and 7.5 pounds per square foot depending on the depth of the corrugation. Maximum length is determined by the practical limits imposed by shipping and handling. Custom widths can be as wide as 50 feet and weigh up to 10 pounds per square foot. Costs for Syntechnics standard width RFP panels range from $15.50 to $20 per square foot. A custom panel of 50-foot width may cost in the range of $50 per square foot.

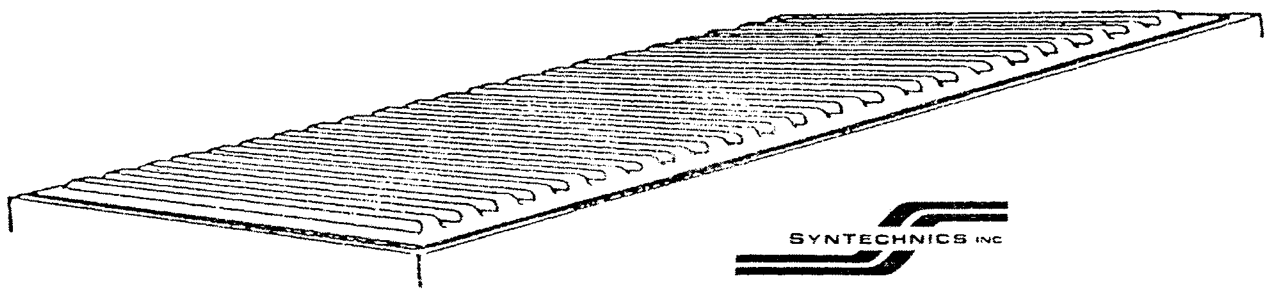


Figure 15

Vertical deployment of RFP panels may be nested in the manner shown in Figure 11. Should an RFP panel be used as part of an enclosure for a floating dry dock, it will be expected to provide a long service life. Therefore, replaceable bolt-on-wearing surfaces may be needed where sliding and nesting panels adjoin

Pretension of Flexible Membrane Systems

Whatever method of deployment is chosen for flexible membrane systems, a method for applying and adjusting tension is needed. The architectural community has developed numerous methods for pre-tensioning the membranes in various types of static structures. These techniques are described very well in two books on tensile architecture; <u>Membrane Designs and Structures in the World,</u> edited by Kazuo Ishi[26] and <u>Soft Shells</u> by Hans-

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[25] Mr. David Schoate, Syntechnics, Inc FRP Division, 700 Terrace Lane, Paducah, KY 42003, Phone: (502) 898-7303

[26] Ishi, Kazuo. <u>Membrane Designs and Structures in the World.</u> Tokyo: Shinkenchiku-sha Co., Ltd, 1999.

Joachim Schock. These examples are instructive but may have limited application for dry dock enclosure because the tensioning systems in static structures only need to adjust for creep or stretch of the fabric over time. Tensioning systems for enclosure in dry docks will need to react to large and dynamic shape changes in the membrane when the system is operated between open and closed positions.

Tensile membranes must achieve equilibrium of forces, i.e. the ability to resist non-uniform applied loads. A flexible membrane resists applied loads by its geometric double curvature combined with the magnitude of its pre-tension load. Pretension is the tension applied to a membrane when the applied loads are at zero. Cost effective dry dock enclosure will require innovative strategies for controlling pretension in membranes. The CMR system is an example of how horizontal movement of the primary support structures can control tension in membranes. For vertical deployment schemes, valley cables are simple and efficient techniques for applying double curvature and pretension membranes. Fig 16 shows how a valley cable is used to pre-tension a membrane. The tensioning winch provides a quick and efficient means of applying and releasing tension in the membrane. This is done without having to provide lateral movement of the primary structural members. Applying tension to the tensioning cable introduces double curvature and pretension to the system. Successful vertical deployment schemes like Figure 16 would use the valley cable to apply pretension and raise and lower the sails.

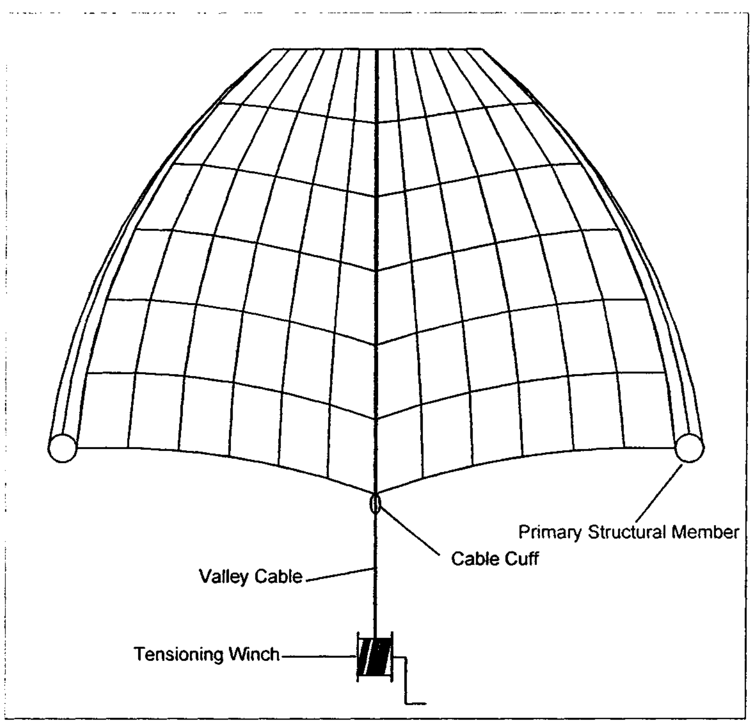

Figure 16

As was mentioned earlier enclosures that rely entirely on air pressure for primary support may not be useful for dry dock enclosure. However, air pressure may be used to adjust pretension and create a double curvature in a membrane surface, see Fig. 17. In static tensile structures, this technique has been used to create an air space for insulation purposes. For a dynamic tensile system as may be used in shipyards, this approach may used to control pretension in membranes that are open and closed frequently.

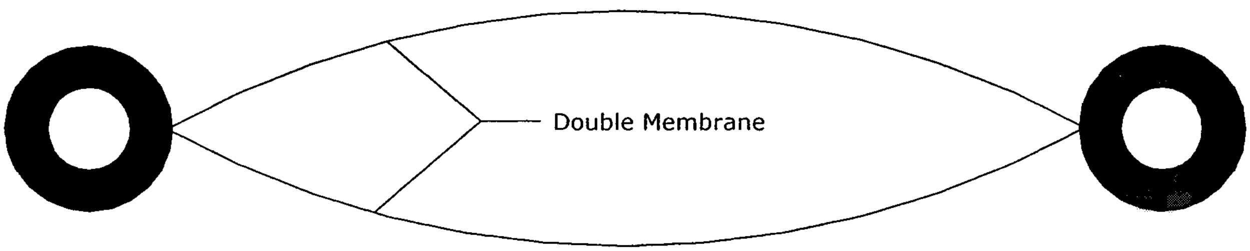

Figure 17

Section 10 CONFIGURABLE TENSILE STRUCTURES

Up to this point, our discussion has focused largely on large, clear span and tensile enclosure systems permanently mounted to a dry dock. It was anticipated that these structures would be capable of enclosing an entire ship and the ship repair processes occurring on or around the vessel while in dry dock. Such an approach represents one end of a range of enclosure strategies that Alaska Ship & Dryock (ASD) is considering for the Ketchikan dry dock. Large free span structures have a high first cost. These same structures, however, will probably have a lower operational cost over time. From a purely operational point of view, a permanently mounted dry dock enclosure is, no doubt, desirable. However, the high front-end cost of providing large-scale enclosure may prevent industry wide acceptance of such an approach.

At the opposite end of the scale, a dry dock enclosure that reduces the initial acquisition cost may be a strategy that is more easily adopted by a greater number of yards. By refocusing on "enclosure of ship repair processes in floating dry docks" as opposed to enclosure of ships in dry dock, another form of enclosure may be practical. Such a system might be classified simply as a pole tent; however, the unique geometry required to enclosure ships may not make them recognizable as such.

The concept introduced by Figure 18 below uses the ship in combination with the dry dock to form the foundation of a two-part enclosure system. In this approach, the ship's top deck is enclosed by a modular system of tensile membrane panels that are joined together with field joints to create a sectionalized membrane large enough to enclose a particular repair project. The underwater body portion of the ship would be enclosed by a system that could mount to the dry dock and extend to, says the main deck of the ship. This approach could provide a readily available, rapidly deployable enclosure for the underwater work and an enclosure system for the top decks that could stay with the ship when it is relocated to a pierside berth.

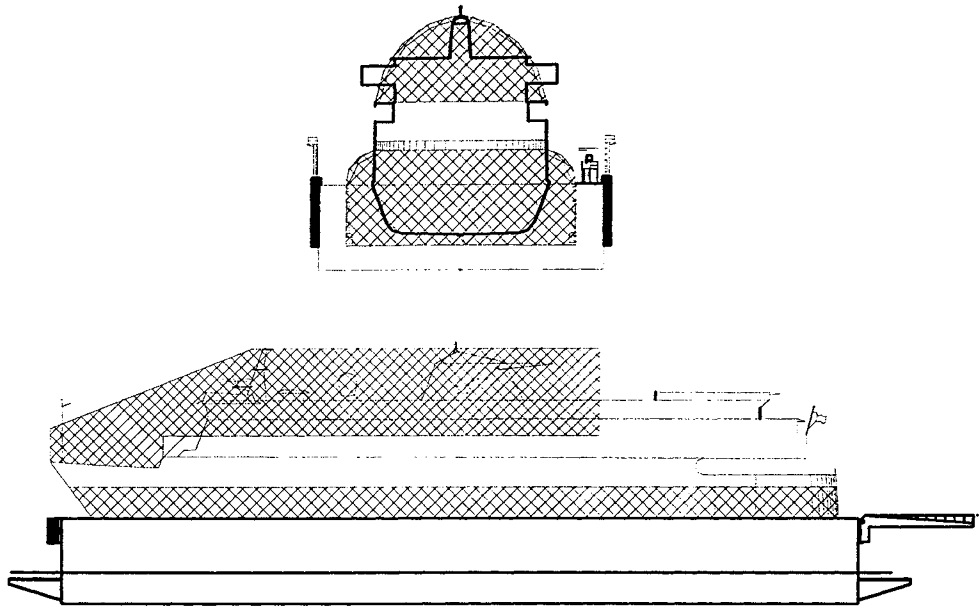

Figure 18
Combination Ship & Dry Dock Mounted Enclosure System

The crosshatched areas of Figure 18 represent enclosed areas of a vessel. This system has several significant advantages compared to a permanently mounted system. The structural span width is significantly reduced which reduces the overall mass and sail area of the enclosure. Since there is a direct correlation between the amount of enclosed volume and total cost of enclosure, this scheme reduces acquisition costs. Dry dock modifications needed to provide a foundation would be minimized again reducing costs. Further, the added sail area caused by enclosing the vessel will not be much different than the exposed area of the unenclosed vessel minimizing the impact on the dry dock stability and structural modifications needed for dry dock anchoring. It also allows enclosure of only those portions of the top decks that are being repaired. If no work is scheduled topside, then no topside enclosure need be assembled. The topside enclosure can be erected pier side or in the dry dock and can remain mounted to the vessel during and after the dry dock evolution allowing pierside surface preparation and coatings operations.

Currently, the most wide spread shipyard practice for this type enclosure employs shrink-wrap supported by scaffolding. Construction of a scaffolding and shrink-wrap system is labor intensive and results in a waste stream of spent shrink-wrap. Deploying, bonding and shrinking shrink-wrap requires dry and calm weather conditions. Development of the proposed configurable pole tent system that can be constructed and removed with reusable materials in moderate wind and rain could provide a low cost enclosure system for ships in dry dock.

A Prototype Ship Mounted Enclosure

The enclosure strategy described above has two major components; 1) enclosure of the underwater body extending from wing wall to the ship and 2) top deck enclosure mounted exclusively to the ship. Alaska Ship & Drydock, Inc (ASD), in cooperation with Mr. Randy McCauley owner of National Tent, Inc.[27] have begun development of a prototype enclosure system for topside work on ships. The class of structure can be described as a sectionalized tensile tent.

The design parameters for this system are driven by the need to develop a ship mounted enclosure system capable of being deployed in light to moderate winds with weather tight field joints. The panels should be small and light enough to be moved into position by hand and erected rapidly using tensile principles to resist applied loads from wind and snow. Tension is to be introduced into the system using appropriate edge control with minimal mechanical or structural complexity. Tension in the system must be adjustable. The structural support system should be comprised of lightweight booms; cables and webbing with end connectors that can easily connected to common ship structures and the structural system supporting the membrane. The deployed system should be able to withstand gale force winds and local snow loads. The membrane sections should be easily produced in quantity by fabric and canvas fabricators. Shipyards could acquire equipment and personnel to manufacture custom weather aprons, seals and special shapes. The entire system shall be reusable.

Edge Treatments & Field Joints

The ASD system makes extensive use of weather tight field joints to construct large membranes from small membranes. Using off-the-shelf technology, ASD is attempting to demonstrate the efficiency of deployment that can be achieved using tensile construction methods. If this first generation of tensile enclosure is successful, ASD will consider developing custom manufactured components that could further reduce assembly time.

Figure 19 is the production drawing for the first generation of sectionalized membrane panels for ASD's prototype enclosure system (ASD System). The drawing in Figure 19 shows a typical 20' by 20' reinforced membrane panel. ASD's initial production run consisted of four 20' by 20' panels and two 10' foot by foot sections totaling 100 lineal feet of membrane 20' in width.

The left and right edges of the panel define the width of the panel and are differentiated by male and female edges that lace together to form a *structural* field joint. The male edge has looped 1,800 pound lacing spaced 12 inches apart and the female edge has grommets to match the lacing pattern of the male edge. A rain flap or *weather seal* overlaps the structural lacing and is secured to the adjacent panel with hook and loop webbing (Velcro) to complete the field joint. The top and bottom edges are finished with Keder and Keder channel. The extruded aluminum Keder channel is stiff enough to impart pre-tension into the sectionalized membrane system sufficient for most operating conditions. Additional D-rings or cable cuffs can be added to either side of the membrane surface for severe loading or furling of the panel sections.

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[27] Randy McCauly, National Tent, Inc. (NTI), 32052 S. Ona Way, Molalla, OR 97038, Phone: (503) 829-5547

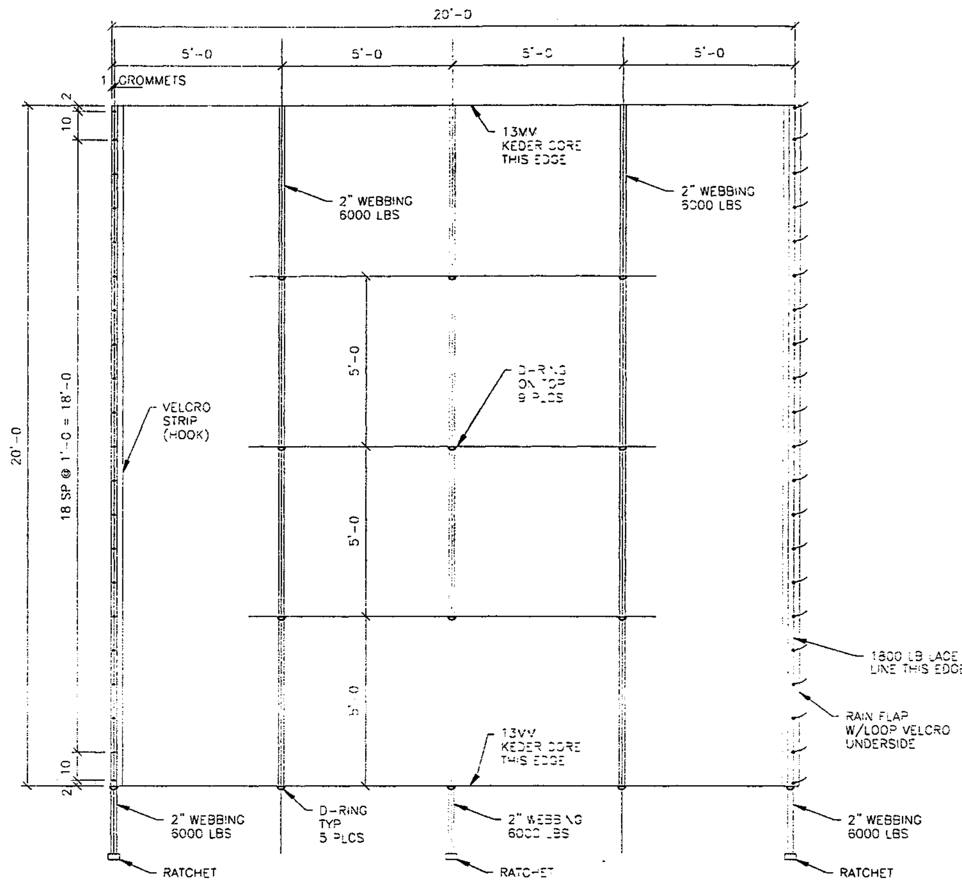

Figure 19
Sectionalized Panel

Figure 20 is a section view of the extruded aluminum Keder channel used for ASD's first generation of ship mounted enclosure systems. The shape of this extrusion is a proprietary design developed by Mr. McCauly, for use with manufactured wood truss joists. ASD will be evaluating performance of the overall system to develop a custom structural section designed for specifically for use in this application.

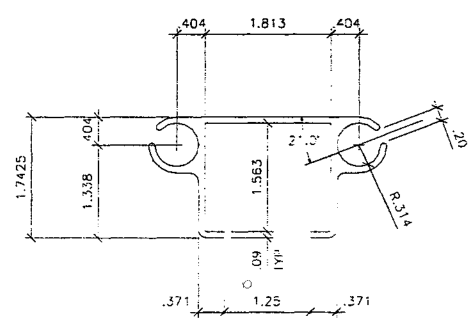

Figure 20: Extruded Aluminum Keder Channel by NTI

The use of common edge treatments, additional panels can be added to the top, bottom, or either side to produce a sectionalized panel membrane of any size. Panel sizes can be varied to fit different ship geometry.

The following photographs of the ASD panel assembly were taken on Friday 11/16/99 aboard the Alaska Marine Highway System ferry Columbia just prior to ASD's first attempt at assembly. Gale force winds occurred a few hours after these photos were taken preventing trial assembly.

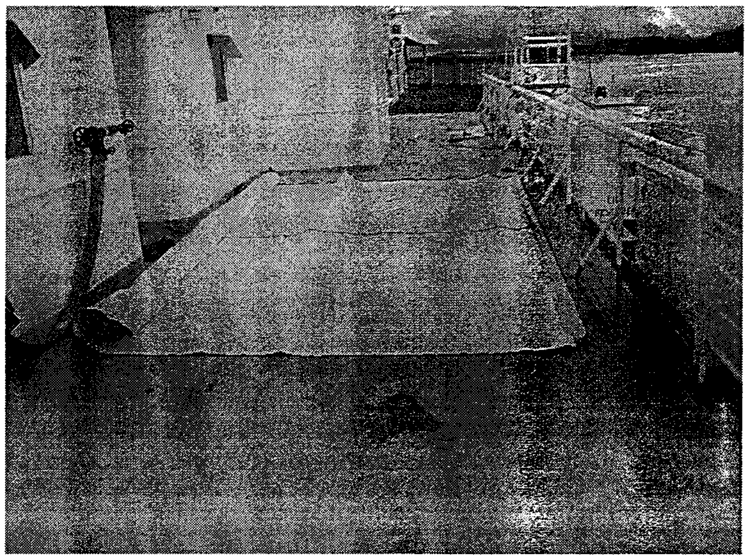

Figure 21
Two 10' Panels Joined to Make a Sectionalized 20' Wide Membrane

Figure 21 show two 10-foot wide panels laced together. The laced field joint runs horizontally in the middle of the panel. The right hand edge of the panel is terminated in the extruded Keder channel.

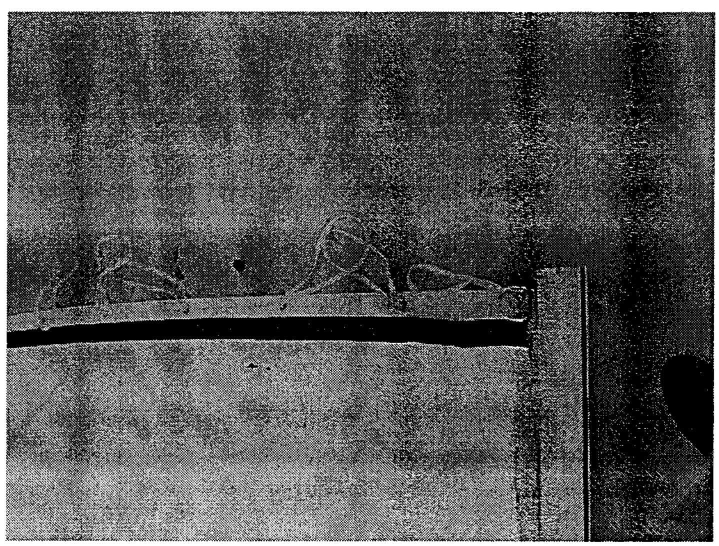

Figure 22: Male edge of panel showing 1,800-lb. lace loops

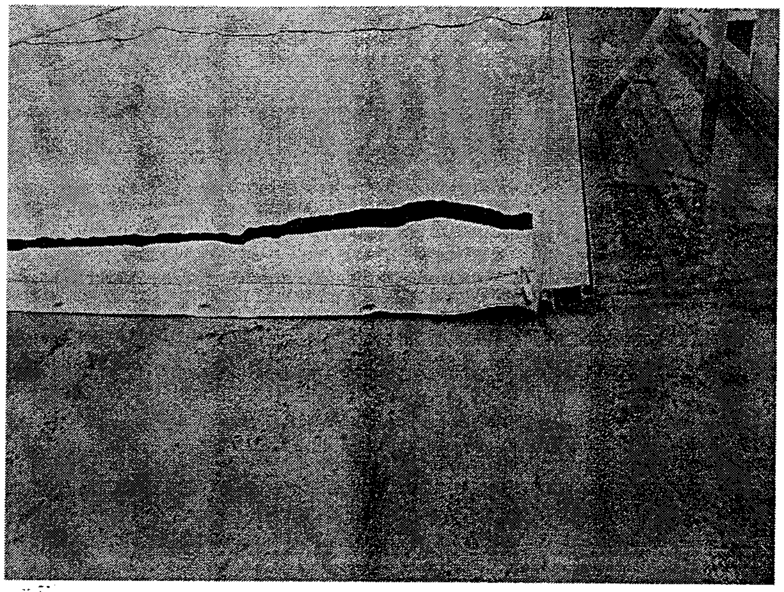

Figure 23: Female edge showing grommet pattern

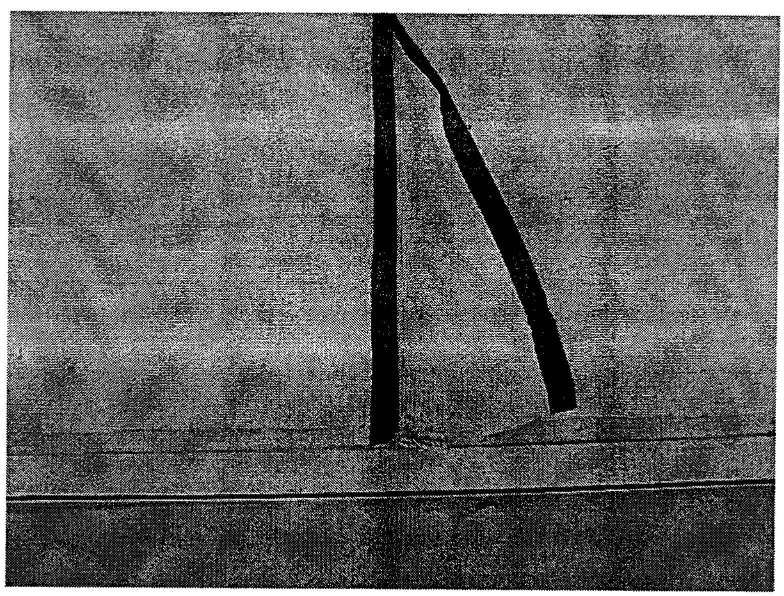

Figure 24
Showing field joint laced together and weather seal open.

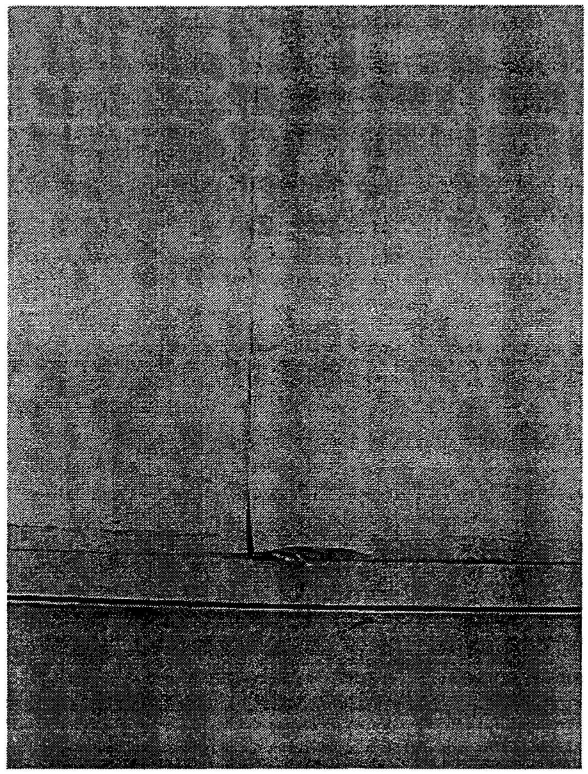

Figure 25
Laced field joint is closed with the Velcor weather seal. Keder channel runs horizontally along the bottom edge

Another approach to field joints that may be incorporated into ASD's enclosure system includes zipper systems. Use of zippers in field joints will require use of separator type zippers where the zipper pull is used like a tool to close the joint. YKK[28], a large manufacturer of zippers, produces a variety of airtight/watertight zippers rated at light, medium, and heavy duty. The medium duty zipper will withstand 80 lbs./ inch cross tension and costs approximately $1.00 per inch. YKK's coil zippers are not watertight but have greater cross tension resistance. Use of coil zippers would require a weather seal over the joint. Mr. Jeff Donnelly of YKK USA, Inc. (510) 644-8106 is providing additional information.

Another manufacturer of high performance zippers, or sealing slide fastener as the manufacturer calls it, is TITEX-TIZIP[29] manufactured in Heldesheim Germany. Their website is located at www.tizip.com. Initial interviews revealed this fastener could

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[28] Mr. Jeff Donnelly, YKK (USA) Inc., West Division, 1808-C 4th Street, Berkeley, CA 94710, Phone (510) 64-4106, Website: www.ykkamerica.com

[29] Mr. Bernd Hulsmann, TITEX Vertriebs-GmbH, Hinter dem Dorge 27 c, D-31139 Hildesheim, Germany, Phone +49 (0) 5121 605587, email hulsintmarket@t-online.de, web site: www.tizip.com

withstand a cross tension force of 150 lbs./inch at a cost of about $0.56 per inch. The inner and outer seals of this zipper are designed to tighten as cross tension on the zipper increases.

Support System

The ASD enclosure system is being developed to protect topside repair processes on vessels in Ketchikan, Alaska. Figure 26 shows the deck configurations of a typical Alaska Marine Highway System (AMHS) vessel moored pierside at the Ketchikan shipyard.

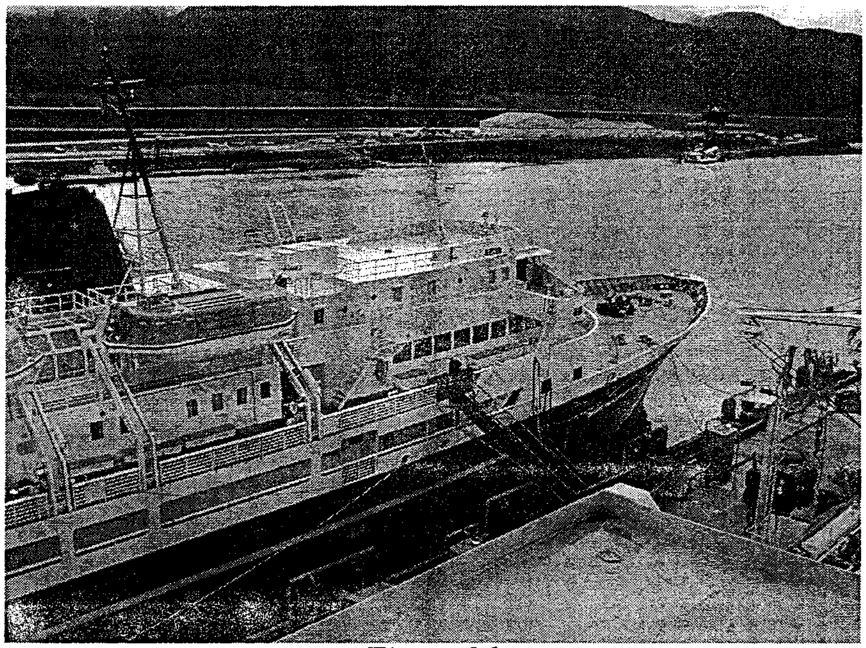

Figure 26
Top Decks of the AMHS Ferry Taku

Figure 27, below, is a section drawing of the of the AMHS ferry Columbia having similar top deck geometry as the Taku shown above. The ASD enclosure system is shown mounted on the port and starboard weather decks.

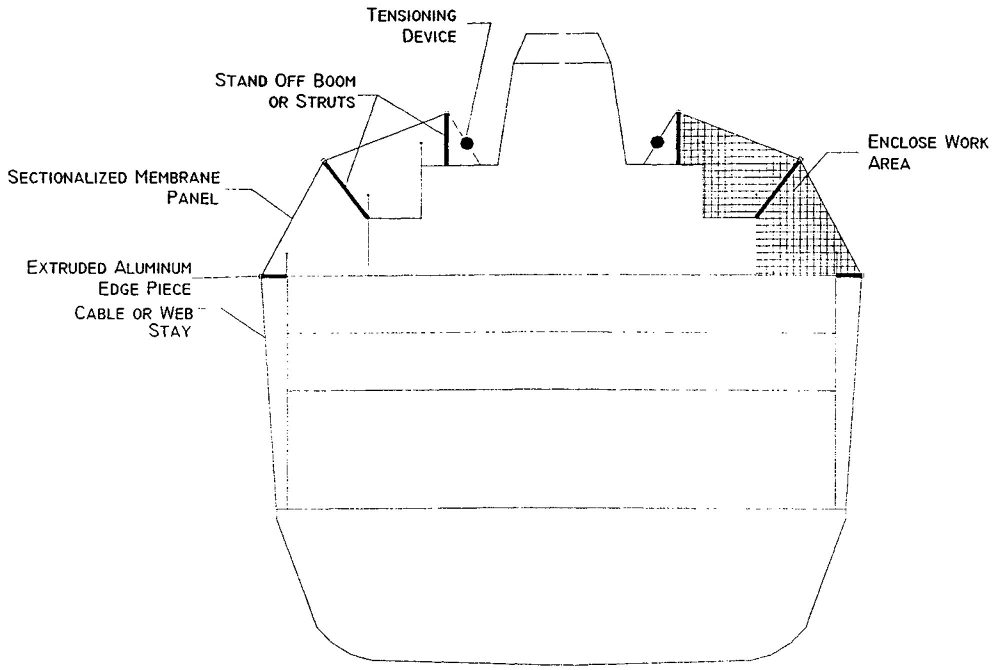

Figure 27: Section View of ASD Enclosure Mounted on M/V Columbia

Figure 27 shows the sectionalized sectional tensioned fabric panels being held-off the weather decks by a series of booms and struts allowing free access to the weather decks and rails. Cable stays provide fixed or deadman anchoring at the bottom. At the top of the system running cable stays with tensioning devices assist in raising the enclosure and provide pre-tension as well as a convenient method to adjust tension. Figure 28 is an outboard view of the area to be enclosed by this first generation of the ASD system.

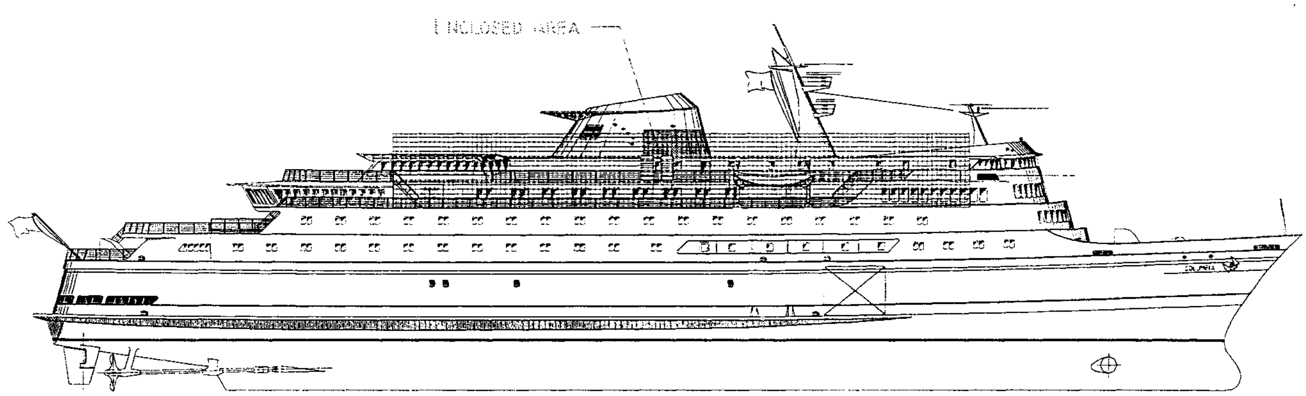

Figure 28
Outboard View of Sectional Enclosure Mounted on M/V Columbia

In the introduction to his recently published book Membrane Designs and Structures in the World, Mr. Kazuo Ishii[30] asserts that because tension structures rely on the concept of tensigrity, all of the components of the structure become more equal in their role of maintaining shape. Therefore, the details and methodology of anchor connections and boundary control become extremely important to the structural integrity of a tensile system. These details are often given less attention than they deserve in assembling temporary or deployable fabric structures. After observing several years worth of attempts at maintaining fabric structures in high winds, it is this authors observation that most failures of these structures are related to inadequate anchors either at the fabric's edge or at the termination of tensioning cables.

The exterior membrane and edge control details are the primary tensile components of the ASD system. In the configuration described above, a series of booms and stand offs provide shape for the membrane and transfer both compressive and up lift loads from the membrane to the foundation, which in this case is the ship. Figure 29 describes the telescoping booms. The booms assist in providing an aerodynamic shape and help prevent ponding. When not in compression, these booms act like tie downs; they transmit tension from numerous locations across the membrane down to the ship. Having a large number of booms (tie downs) will reduce the magnitude of the load being transferred to the edges of the membrane, which in turn reduces the load on the tensioning system. At the top of the boom are connections that can lock into either the extruded Keder channel, as shown on the left of Figure 29, or connect directly to the fabric panel as shown on the right.

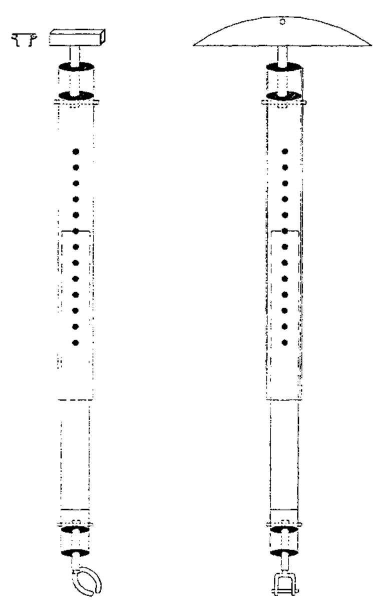

Figure 29 : Support Booms or Stand Offs

[30] Ishii, Kazuo. Membrane Designs and Structures in the World. Tokyo. Shinkenchiku-sha Co., Ltd., 1999.

The mushroom head distributes compressive loads from the fabric panel over a large surface area to distribute point loads in the membrane.

A slot in the top of the mushroom would accept D-rings attached to the panel and a pin type locking mechanism will anchor the fabric to the boom to resist uplift and fluttering. The steel mushroom shape may be readily available from hot water tank or boiler manufactures that use a similar steel shape for end walls of tanks.

The shafts of the booms will be telescoping and locked into place with pins. The purposes for telescoping booms include gross adjustments of length to accommodate varying ship geometry and the ability to extend if tension adjustments are required. Adapting fixed screw jacks between the bottom of the boom and the fitting could facilitate tension adjustment under load.

The bottom fittings will be constructed of mechanisms that can quickly attach to typical steel shapes found on ship's superstructures to resist uplift or tension forces. Development of a quick disconnect system for the end fittings will reduce the number booms required to be kept in stock. Typical shapes to which these fittings must be able to adapt include flat plate, pipe, hand and safety rail, masts and cables. Figures 30 & 31 show two readily available fittings[31] that can adapt to tubing, as is typical of hand railings on ships, and flat plate, as may be found on deck combing plate.

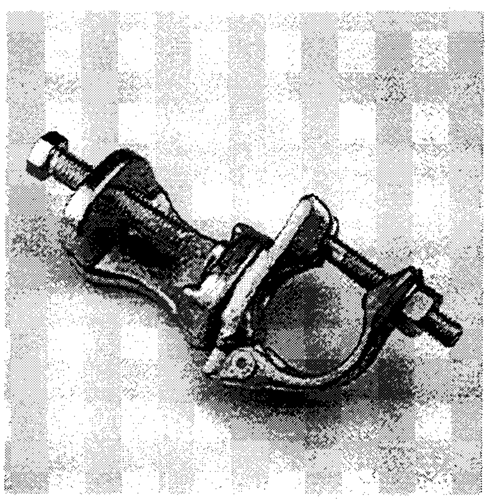

Figure 30[19] - Beam Clamp

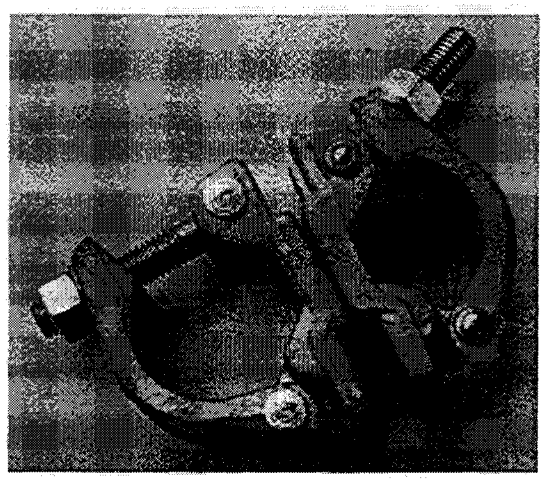

Figure 31[19] - Swivel Scaffold Clamp

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[31] Photo in Figure 19 & 20 & 21 obtained from web page located at http://www.edgeintl.com and provided by Edge Scaffolding, Crown Valley Pkwy. Suite #273,Laguna Niguel, CA 92677 USA, Phone:(714) 495-5666

The beam and scaffold clamps can fitted to hand railings or scaffold tubing as designed. They can also be cut in half and modified to provide a quick disconnect fitting between the telescoping booms and typical railings and pipe structures. They can also be used for their intended purpose, which is to join scaffold tubing. Scaffold tubing assemblies may be useful for end-wall enclosure, weather seals, special stand-offs, or custom structures to accommodate penetrations of the sectionalized membrane. The beam clamp is capable of griping combing or other flat plate structures to cable anchor terminations or quick disconnect fittings at the bottom of the booms. Other quick fit mechanisms could include web ratchets for large diameter structures like masts.

Figure 32 below shows an internal connector called a *split joint pin,* also supplied by Edge Scaffolding that will be useful in butt jointing scaffold tubes where a smooth joint is desired.

Figure 32[19]
Split Joint Pin

The entertainment industry provides another source of commercially available, quick connect fittings. These products are designed for speed and ease of use in temporary set up situations like stage productions. Doughty Engineering[32] provides a unique variety of aluminum clamps and bracketry for tubes, pipes girders and trusses. Many of the tube clamps have quick connect inserts and a unique line of "Overlockers" appears to be very secure clamps for tubing. Included in the catalogue are girder clamps, scaffold clamps, suspension clamps, specialty couplers, hook clamps, pulley blocks, and other rigging mechanisms that may prove useful in shipyard applications.

Another useful source of components from the entertainment industry is a line of lightweight, trusses from TOMCAT USA, Inc.[33], a manufacturer of staging, lighting and support systems. The TOMCAT aluminum trusses and towers can be folded for storage and handling ease and quickly erected to provide support for tensile tent assemblies.

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[32] Doughty Engineering Limited, Crow Arch Lane, Ringwood, Hampshire...BH24 1NZ, Phone 44 (0) 1425 478961, Web site: www.doughty-engineering.co.uk

[33] Tomcat© USA, Inc. P.O. Box 550, Midland, TX 79702. Mr. Keith Bohn, Asst. U.S. Sales Manager, Phone (915) 694-7070 ext. 25. Fax (915) 689-3805. E-mail: kbohn@tomcatusa.com.

Weather Seals

To this point, the discussion of the ASD prototype enclosure system has described a method for enclosing relatively large areas of a ship. Because of the need to both pre-tension and post tension the membrane system uniformly, the overall shape of the system must be uniform. Rarely will a ship's superstructure allow a completely uniform shape to enclose all of the structures to be coated or repaired. Details will need to be developed for specific conditions such as the end walls, weather seals along the longitudinal edges and techniques to accommodate structures that must penetrate the main enclosure.

Weather seals along the longitudinal edge of the system need not be held under as much tension as the main enclosure if surface area is kept to an absolute minimum. Attaching anchor cables or webbing to the aluminum Keder channel provides the opportunity to employ a low-tension weather seal as shown in Figure 33 below.

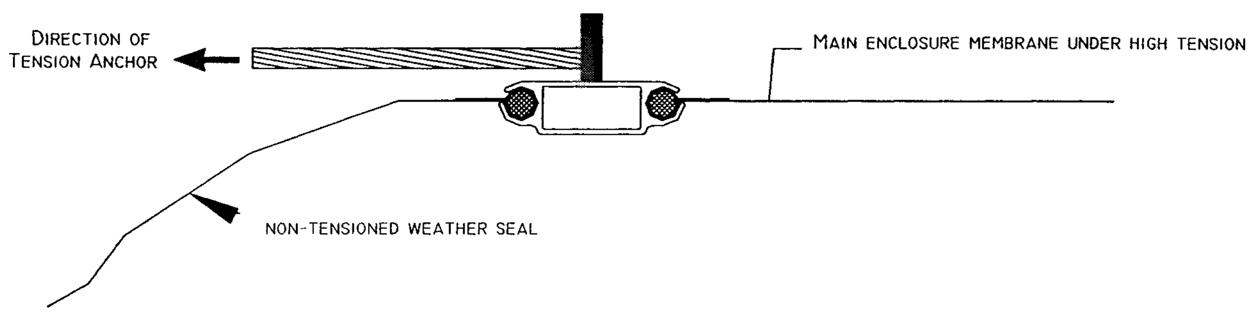

Figure 33
Transition to Non-tensioned Weather Seal

The Keder and Keder channel provides a weather tight transition from the highly tensioned, uniformly shaped main enclosure, to the low-tensioned, non-uniform shaped weather seal. Special techniques must be developed securely anchor the weather seal to the ship superstructure. The precise method of creating this weather seal will be determined by the shape and finish of the structure, the repair process occurring in the enclosure, and surface area of the weather seal. Shrink-wrap tape may suffice for low tension conditions but often more mechanically positive and secure seals will need to be developed.

One approach to develop a minimally tensioned weather seals is to create foam filled cuffs in the edge of the non-tensioned membrane. The foam would surround a cable that could be anchored at its ends to secure the system. Figure 34 shows how this system might work. Another adequate type of weather seal could be constructed using watertight cuffs. The cuffs would be filled with water. The weight of the water would provide pre-tensioning and the forces needed to maintain a weather-tight seal.

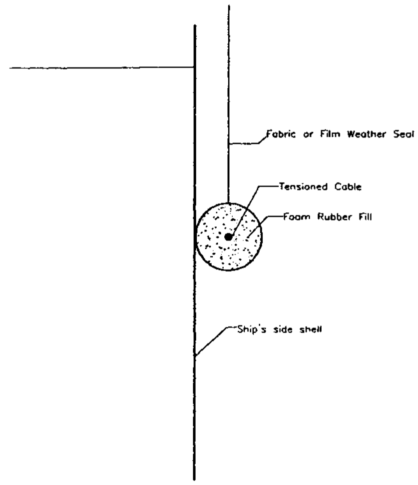

Figure 34: Foam Filled Weather Cuff

Weather seals on horizontal decks can also be achieved with water filled fire hoses or manufactured water dams. Water Structures Unlimited[34] manufactures a tube about 12 inches in diameter that is baffled in the middle to prevent rolling on horizontal surfaces, see Figure 35. If fire hoses are used, laying two hoses side by side and banding them together will help prevent rolling. Water filled tubes can also be used to help control surface water on weather decks to prevent water from entering the enclosure.

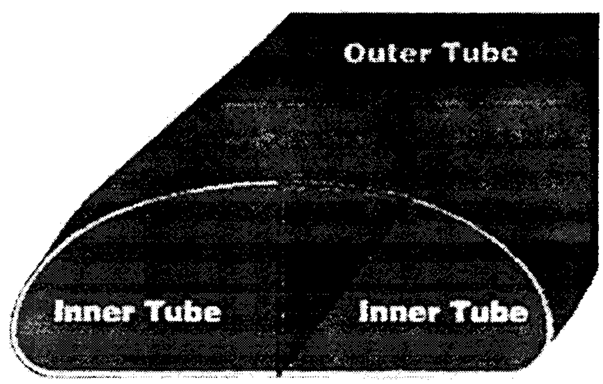

Figure 35, Water Structures Unlimited Aqua Dam

To reduce initial development costs, ASD's initial prototype system will be constructed with as much *off- the- shelf* material as can be located. After gaining experience using these readily available materials, custom shapes and fittings will be developed to create an optimal enclosure system for use in shipyards. An obvious limitation of the first

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[34] Water Structures Unlimited, Phone: 800-693-5055, Fax: 707-768-2116, E-mail: wsu@humboldt1.com

generation of the ASD prototype system is the lack of double curvature in the membrane. Remember double curvature is required to provide equal tensions across the surface of a membrane. Because the ASD panels are essentially flat, greater pre-tension will be required to resist flutter than if the system employed double curvature. Because greater tension in the system is required by the flat shape, a greater number anchor points may be required than if the system were appropriately curved. Subsequent generations of ASD developed enclosure will attempt to introduce double curvature to the system.

Dry Dock Wing Wall to Ship

Developing an effective enclosure system for underwater and side shell structures of vessels will be required to provide total enclosure of a vessel in dry dock if the ASD system is adopted for top sides. Two distinct approaches to enclosure of the underwater body are being developed by Rapid Deployable Systems (RDS)[35] and Mr. Robert Davis[36] of Curtain Total Containment. The RDS system employs a movable shed with work platforms at useful elevations. The shed provides full height containment with weather seals along its edges. It is moved along the floor of the dry dock and coatings are completed within the enclosure. Mr. Davis' approach is based on cable supported curtains extending from the wing wall to the ship running the length of the vessel.

Adapting an enclosure strategy that allows the ship mounted enclosure to stay with the vessel will provide opportunity to shorten dry dock periods for vessels that require significant topside work. Since topside coatings operations can take longer than underwater body coatings, these projects may be completed pierside.

ENCLOSURE REQUIREMENTS FOR THE KETCHIKAN DRY DOCK # 1

Description of the Ketchikan Dry Dock #1

Ketchikan Dry Dock #1 is a floating dry dock with a 10,000 long ton capacity. The geometry that is pertinent to a future enclosure for this dry dock is shown in Figures 1 and 2. Displacement of the dry dock is 6,200 long tons. An 11-ton traveling crane is mounted on the starboard wing wall. Transverse positioning of ships in the dry dock is accomplished by six capstans; three on each wing wall. Certification for the dry dock is renewed annually with a safe dock report prepared by an independent marine engineer

[35] Rapid Deployable Systems LLC, 2061 Avenue B North, North Charleston, SC 29405. Phone (943) 740-1833 email: rdsllc@bellsouth.net

[36] Mr. Robert Davis, Curtain Total Containment, 200 Holland Drive, Camden, NC 27921, Phone (252) 333-1458

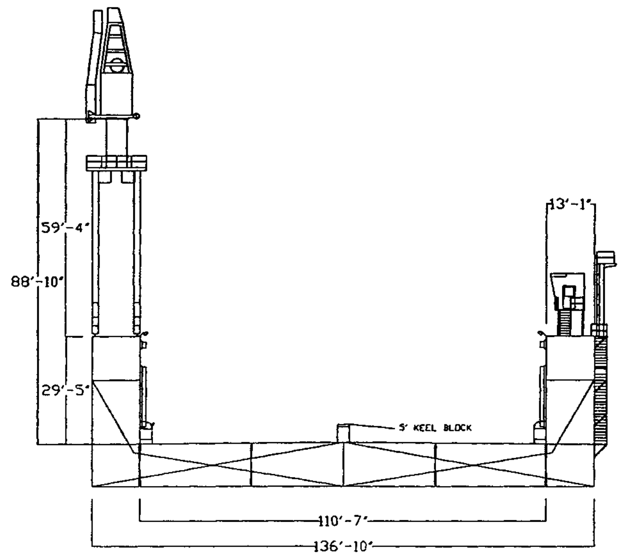

Figure 1
Section View of Ketchikan Dry Dock #1

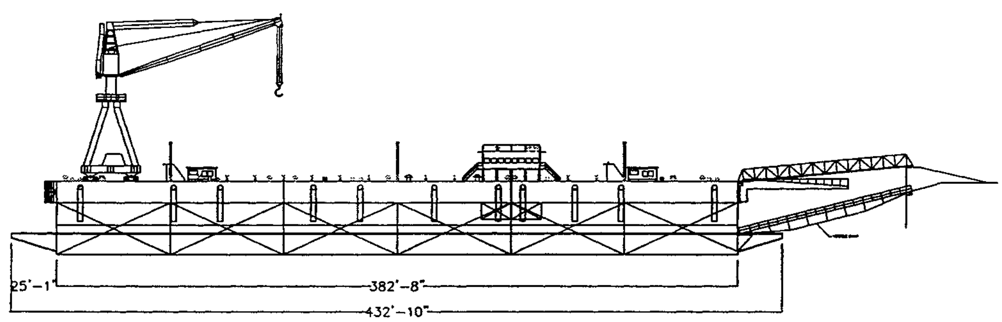

Figure 2
Outboard View of Ketchikan Dry Dock #1

The Ketchikan dry dock is owned by the state of Alaska. It was designed primarily to serve the Alaska Marine Highway System (AMHS) ferries. AMHS ferries have shallow drafts and high, wide superstructures. The largest AMHS ferry has a docking displacement of just over 6,000 long tons. Extra width was built in to the Ketchikan dry dock to accommodate 400 foot by 100-foot barges that transport freight to and from Alaska. Because of this added width, the Ketchikan dry dock has an excess lifting capacity of about 3,000 long tons. This excess lifting capacity is available to support the live and dead loads of a dock mounted enclosure system. However, the relatively low wing walls in conjunction with the high and wide superstructure of the AMHS vessels provide the enclosure designer with the added challenge of providing rather tall sidewalls for enclosure of ships.

The largest vessel in the Ketchikan dry dock's service fleet is the AMHS ferry M/V Kennicott. This vessel has a docking displacement of 6,156 long tons. Its overall dimensions are 380 feet LOA. The breadth is 85 feet. When on blocks, the vessel has a height of 82 feet above the dry dock wing walls. The highest and widest dimensions for the Kennicott occurs at the bridge wings where she is 94 feet in breadth at a point 57 feet above the top of the wing walls. The outboard section and profile views of the M/V Kennicott in dry dock are presented in Figures 3 and 4.

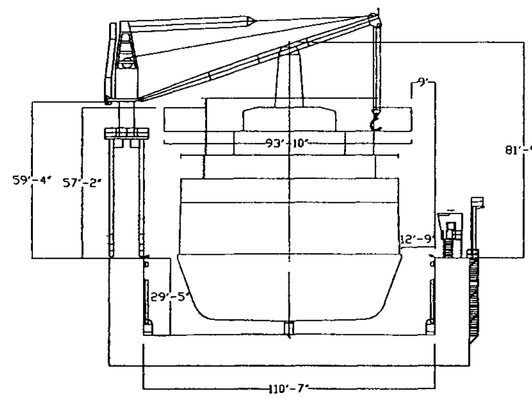

Figure 3: Section of the M/V Kennicott in Dock

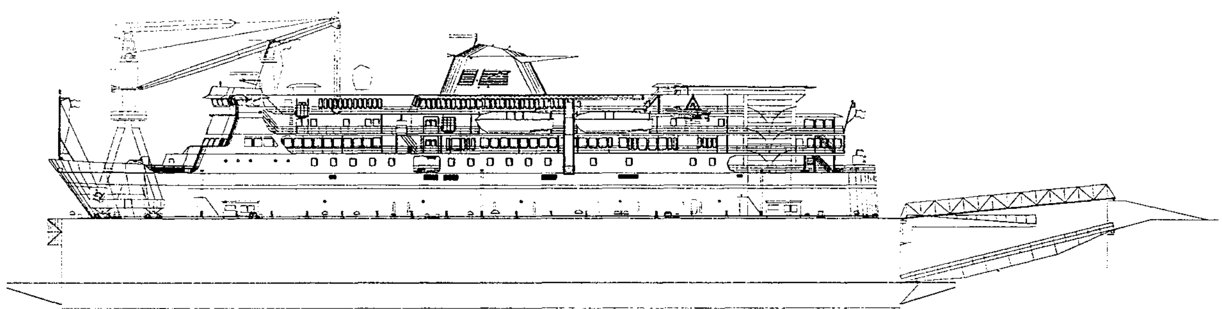

Figure 4: Outboard View of the M/V Kennicott in Dock

Stability

It is important that dry dock enclosures do not impair stability of the dock at any period of a dry dock evolution. The dry dock evolution begins when the dock is initially submerged to lift a vessel and continues through the ship lift phase, the repair period, the launching period and finally, raising the empty dock to prepare the blocking for the next vessel.

Stability is affected by the location of the center-of-mass and the location and magnitude of applied forces. Floating independently, both a ship and a dry dock have their own centers-of-mass. When in dry dock, a common center of mass must be calculated for the dry dock and the ship. If a particular enclosure concept adds weight and sail area to the combined ship and dock system, then these factors must be included in the calculation of center-of mass. Knowing the center-of-mass for the total dry dock system, i.e. the dock, the ship, and the enclosure is critical to predicting the stability of the dry dock at any point in the dry dock evolution. The magnitude, type and direction of wind and snow loads are important in assessing the center-of-mass and stability.

Stability issues are factors that will affect the selection of appropriate dry dock enclosure strategies. In this and other reports, the author has proposed a number of enclosure concepts to the reader. These concepts can be organized into four general approaches. These are:

1. A ship mounted system, e.g. shrouding or a tent that encloses the work area;
2. A structure that is supported by the floating dry dock wing walls and the ship;
3. A structure that will enclose the entire work area, i.e. it is supported by the wings of the floating dry dock and has a clear span high enough to miss the upper mast of the ship; and
4. Combinations of the above three ideas.

Both stability and flexibility of the floating dry dock are important considerations. For any system, the stability of the combined <u>dry dock-ship-structure</u> should be investigated. Further deformation limits of the floating dry should be checked when the enclosure is in place.

First, consider approach 1, a ship mounted system. The ASD system using a lightweight tensile tent mounted to the ship is an example of this concept. This low height, lightweight system minimizes changes to the center of gravity for the enclosed ship and dry dock. In addition, it is anticipated that any added loads for this lightweight system will not negatively impact deformation limits of the dry dock. Therefore, it is reasonable to assume that this type of system will not appreciably affect dry dock stability.

Now consider approach 3, a very large structure mounted to the dry dock. This approach will have affects on the system's center of gravity. For example, wind and snow load on a large free-span structure may require structural modifications of the foundation (the floating dry dock) and its mooring system. It is hoped that the following presentation will help the reader understand the influence a large free-span structure may have on the stability of an enclosed floating dry dock.

Stability of the combined ship and dry dock system is evaluated for two periods during the dry dock evolution. The first period is the most critical. The risk of instability is the greatest at this time; it occurs during docking and is referred to as Condition 3. More precisely, Condition 3 exists while the dry dock is lifting. That is, from the time the water level is at the top of the keel blocks until the main deck breaks water surface, see Figure 5. During Condition 3, only the free surface area of the water in the wing walls supports the dry dock. The second point for stability evaluation is known as Condition 5; the most stable position for a floating dry dock, see Figure 6. Condition 5 exists when the main deck of the dry dock raises at least one foot above the water line. At this position, the surface area of the water supporting the dry dock extends the full width of the dry dock, a much more stable condition. Condition 5 exists until the launching operation brings the system back to condition 3. Condition 3 exists until the vessel hull enters the water thereby reducing the load of the combined ship and dry dock system.

The structural stability for floating dry docks is a function of distances between centers of gravity of the ship and the dry dock. For the purpose of this discussion, the term *vessel* shall refer to the combined ship and dry dock. Stability of the *vessel* is measured by the metacentric height (GM) above the keel of the vessel. The word keel will mean centerline of the bottom of the dry dock. The center of gravity G is the point at which "all the vertically downward forces of weight of the *vessel* can be considered to act or the center of mass."[37] The metacenter, M, "is the highest point to which G may rise and still permit the vessel to have a positive stability." The metacentric height, GM, then is the distance between G and M. The GM must be at least 5 feet as this is the allowable safe height for GM during docking of a vessel. Values of GM below 5 feet and approaching zero are less stable and reduce the safety margin during docking. The dock is unstable for values of GM < 0.

Stability for a specific ship will be presented as an example. Consider the M/V Kennicott on the Ketchikan Dry Dock #1. This is the largest ship in the Ketchikan dry dock's service market and will represent a worst case condition for evaluating dry dock stability with a large enclosure mounted on the Ketchikan Dry Dock #1.

Figure 5 below represents the M/V Kennicott and the Ketchikan Dry Dock #1 in Condition 3, the least stable position. The blocks are carrying the entire weight of the vessel and the main deck is still submerged.

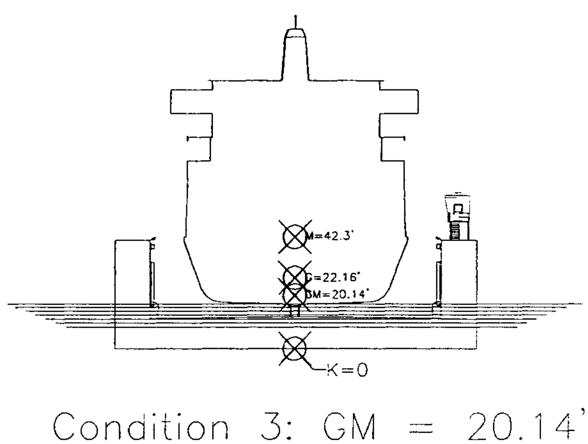

Figure 5

In Figure 5, K = 0 feet, the keel of the dry dock. So, how is GM calculated? It is the difference between M and G; GM = M – G = 42.3' – 22.16' = 20.14'. Where, G is the center of gravity and M is the highest position to which G could rise. For this condition,

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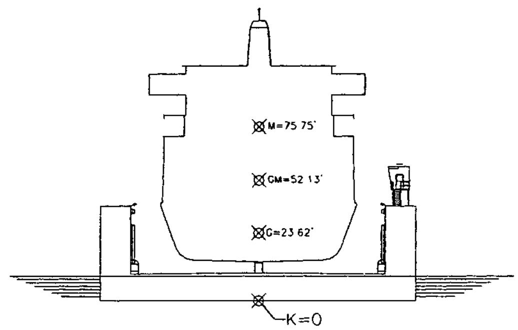
[37] Ladage, John, and Van Gemert, Lee. Stability and Trim for the Ship's Officer. Cambridge: Cornell Maritime Press, Inc., 1956.

metracentric height GM = 20.14 feet, which exceeds the 5-ft minimum. This means then, that the unenclosed dock can safely lift the M/V Kennicott.

Figure 6 shows Condition 5 for the M/V Kennicott and the Ketchikan Dry dock #1.



Condition 5 GM = 52.13'

Figure 6

In Figure 6 the main deck of the dry dock has broken the surface of the water and the surface area of water supporting the *vessel* extends across the entire dry dock. As would be expected, with the surface of the water extending entirely across the horizontal plane of the dry dock, a more stable condition exits. Calculation of the metacentric height shows the GM is now at 52.13'; a more stable condition than when the vessel was in Condition 3.

This example illustrated the stability conditions for the largest expected ship that will be lifted on the Ketchikan Dry Dock #1. The conditions for other, smaller ship will be more stable. Mr. Robert Heger[38] developed a set of graphs to describe the allowable vertical centers of gravity for a range of possible enclosure weights, see Figs. 7 and 8. Since a permanently mounted dry dock enclosure will remain on the dry dock throughout the docking evolution, Mr. Heger calculated allowable vertical centers of gravity for both the stable and potentially unstable conditions.

[38] Mr. Robert Heger. Heger Dry Dock, Inc. 13 Water Street, Holliston, Massachusetts 10746. Telephone: (508) 429-1800. E-mail: drydockter@aol.com.

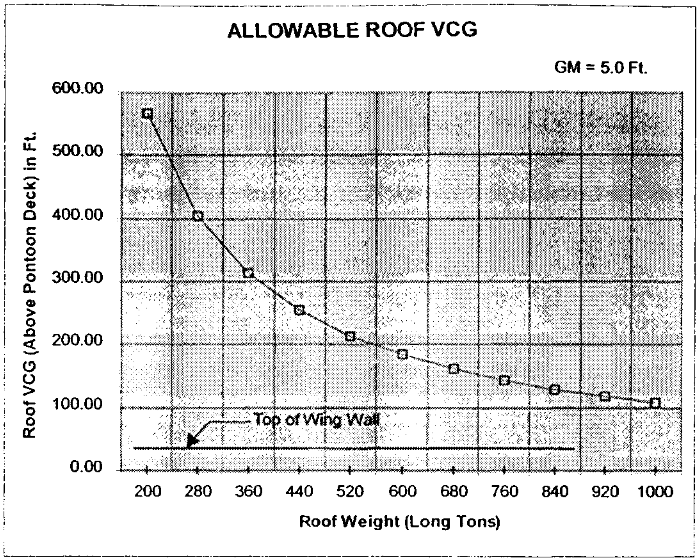


Figure 7: Condition 3, Least Stable

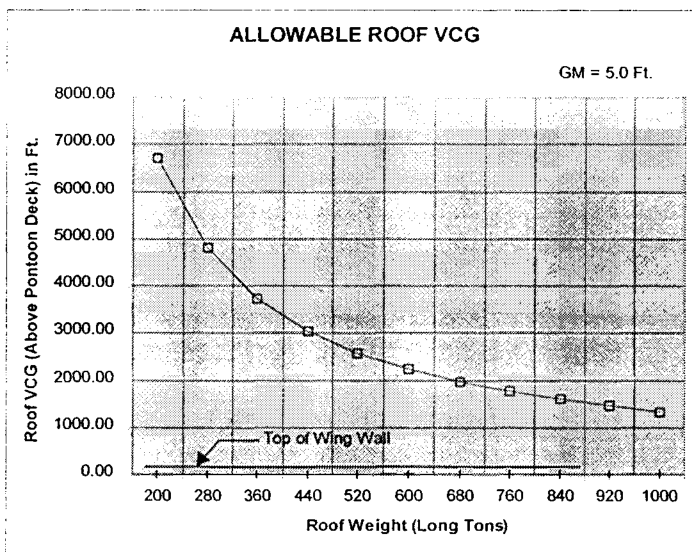


Figure 8: Condition 4, Most Stable

Mr. Sid Morrell of Satellite Shelters[39] estimated the weight of a nesting Rubb building capable of enclosing the M/V Kennicott in the Ketchikan dry dock to be approximately 400 long tons. That weight includes the weight of the rails. For condition 3, the allowable vertical center of gravity for the enclosed *vessel* must be no greater than 280

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39 Mr. Sid Morrell. Satellite Shelters, P.O. Box 1930, Port Townsend, WA 98366. Telephone (360) 379-9718

feet above the main pontoon deck, see Fig. 7. For condition 5, the vertical center of gravity of the enclosed *vessel* can approach 3,500 feet, see Figure 8.

Where this may, at first glance, seem an excessive height for a dry dock enclosure, it should be remembered that these values for vertical center of gravity do *not* take applied wind and snow loads into account. However, for the static condition, dry dock enclosure appears feasible.

To evaluate the feasibility of a very large enclosure, consider the wind pressure on an enclosure over the MV Kennicott on the Ketchikan dry dock. The author asked Dr. Hulsey[40] to assume for this example that the enclosure is shaped to shed snow, removing the potential for snow loads. Dr. Halsey's analysis follows.

The 1994 Uniform Building Code (UBC) provisions may be used to approximate wind pressure at the Ketchikan dry dock. So, in Ketchikan the wind speed for the *design fastest mile* at 33-ft above ground is estimated to be 100 mph. The exposure at the floating dry dock is assumed to be exposure D. The enclosure shall be considered a partially enclosed. Subsequently, the wind pressure at a given height is given by

$$P = C_e\, C_q\, q_s\, I_w$$

Where C_e is a coefficient that accounts for height and gusts, from Table 16-G of the UBC. This coefficient increases from 1.39 at heights 0-30 ft to 1.93 for heights between 100 ft and 120 ft. UBC Method 2 may be used to approximate the lateral pressure coefficient for lateral stability calculations. The lateral pressure coefficient using Method 2 for a frame structure is $C_q = 1.4$, Table 16-H of the UBC. This coefficient accounts for both the pressures on the windward wall and a vacuum on the leeward wall. A basic wind pressure for a wind speed of 100 mph is provided in the Table 16-F of the 1994 UBC. This pressure is q_s=25.6 psf. It is assumed that the floating dry dock will meet the requirements for a standard occupancy. Therefore, $I_w = 1.0$, see UBC Table 16-K. Neglecting uplift and aerodynamics associated with membrane structures, the lateral wall pressure may be approximated by

$$P = (C_e)\,(1.4)(25.6)(1.0) = 35.84\,(C_e)\text{ psf}$$

The following table illustrates that the overturning moment acting on this floating dry dock may be 80,148 ft-tons. This is for a rectangular enclosure that is 114 ft high and 380 ft long. No provisions were made for uplift forces acting on the roof system. Further, the overturning moment will add about 589 tons to one side of the dock and an uplift of the same amount on the apposite side. That is, the vertical forces imposed by wind are found by dividing the overturning moment by the width of the dock or,

(80,148 ft-tons/136 ft = 589 tons).

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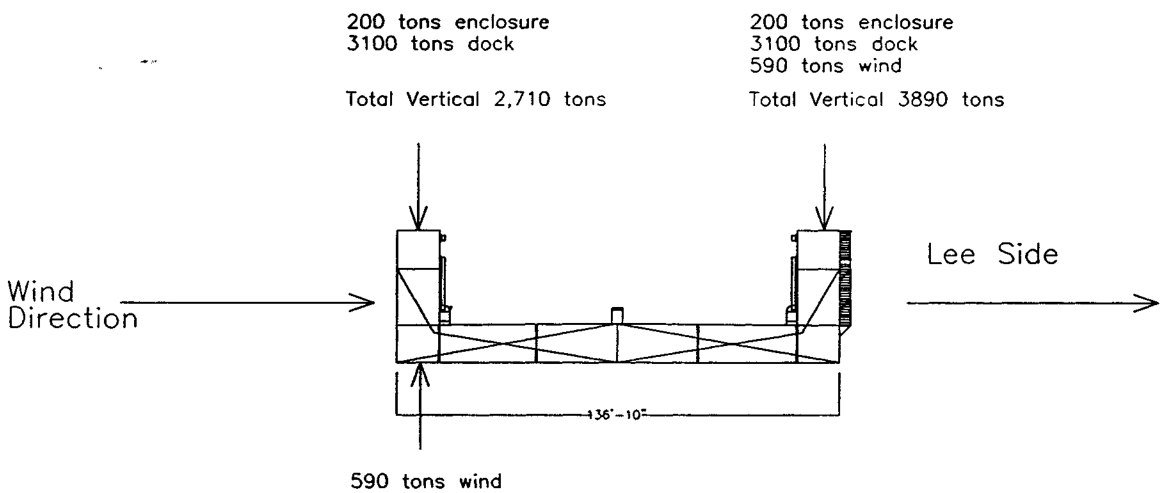
[40] Dr. J Leroy Hulsey, University of Alaska – Fairbanks, Civil & Environmental Engineering, Rm. 246 Deckering Building, 306 Tanana Drive, Fairbanks, AD 99775. Phone (907) 474-7330

Wall ht (ft)	Ce	P(psf)	Wall area (sq ft)	Lateral Force (tons)	Force above ground (ft)	Overturning Moment (ft-tons)
0	1.39	49.82	5,700.00	142	7.5	1,065
15	1.45	51.97	1,900.00	49	17.5	864
20	1.5	53.76	1,900.00	51	22.5	1,149
25	1.54	55.19	1,900.00	52	27.5	1,442
30	1.62	58.06	3,800.00	110	35	3,861
40	1.73	62	7,600.00	236	50	11,781
60	1.81	64.87	7,600.00	247	70	17,256
80	1.88	67.38	7,600.00	256	90	23,044
100	1.93	69.17	5,320.00	184	107	19,688
114	1.93					
Totals				1,327		80,148

A quick check of applied, or live, loads for exposed surface areas may prove useful at this point. The following drawing shows the force vectors and their magnitudes.



The worst condition for possible overturning for a fully enclosed dry dock will be when the dry dock is floating with no ship, no snow load and maximum wind gusts. This condition could occur and should be evaluated.

The drawing above shows the net forces that will work on 100-foot high sidewall mounted on the dry dock. The left side is trying to lift out of the water and its total acting downward load is the sum of one-half the self weight of the enclosure, one-half the self weight of the dry dock and an uplift weight of about 589 tons. The right side is being pushed into the water. Therefore, the loading acting downward on the right side of the dry dock is one-half the self-weights of the enclosure and dry dock and a down drag of 589 tons. Thus, the water-foundation must support 2,711 tons on the left and 3,889 tons on the right.

Assuming differential vertical movements or racking of the dry dock under these extreme wind conditions are acceptable, the structure will be stable. It is important that sufficient provisions be made to prevent the floating dry dock from moving under a lateral wind force of 1,327 tons. That is, the structure must be restrained so it does not move under these wind conditions.

It would be prudent to design the enclosure to shed snow build up. This could reduce the influence of the snow loading. These measures would need to be tested and coordinated with the local building officials. Providing a steeply sloped, slippery surface could significantly reduce the snow load. Yet, provisions for this are not generally provided for in the local building code. Reducing the snow load alone would appear to bring the total weight of the system to with in allowable limits for enclosure of the Kennicott. Providing a more aerodynamic shape may also reduce wind loads and the values estimated above were for wind loads against the entire length of the enclosure. As discussed in earlier reports to this project, evaluating wind loads on tensile structures is complex and often performed with wind tunnel testing. Determining actual wind loading on this system is beyond the scope of this report, but these very rough estimates of applied loading indicate that the Ketchikan dry dock appears to have sufficient stability for such a large enclosure.

Weather & Climate

ASD's interest in developing cost-effective enclosure for work on ships in dry dock is driven by the local climate. A brief review of the climate data presented in Table 1 and 2 below reveals that there is a critical need for enclosure in Ketchikan. The Ketchikan average annual rainfall is 150 inches. Thus, it is reasonable to assume 0.01 inches of precipitation will occur on at least fifteen days of every month. Snow in excess of 1-inch is possible in seven months out of every year. Wind gusts of at least 50 miles an hour can be expected 11 months out of the year with the gusts of at least 49 miles and hour during the least windy month. Clearly, wind and rain have significant impacts on ship repair processes and production scheduling at the Ketchikan shipyard.

Local climatic conditions negatively impact production schedules for the ship repair and ship building business in Ketchikan. This has a significant influence on the potential benefit/cost analysis for an enclosure at this shipyard. For example, what might be economically justifiable for Ketchikan may not be economical for other geographic localities.

The live loads applied by wind and snow are of critical concern to the design of all structural systems, especially tensile structures. Local building codes require permitted buildings to be designed to withstand 100 mph winds and snow loads of 30 pounds per square foot. A review of the climate data in Table 1 and 2 supports these design standards. The probability of precipitation curve in Table 1 will be useful in benefit/cost analysis of various enclosure strategies. The weather data in Table 2 will be useful in when designing enclosures for the Ketchikan floating dry dock. For example, the mean wind speed may be helpful in determining the force limits at which the enclosure may be deployed.

Table 2 is a compilation of data from the Annette Island and the Ketchikan Airport reporting stations. The data was obtained from the Western Region Reporting Center located on the Internet at http://www.wrcc.dri.edu.

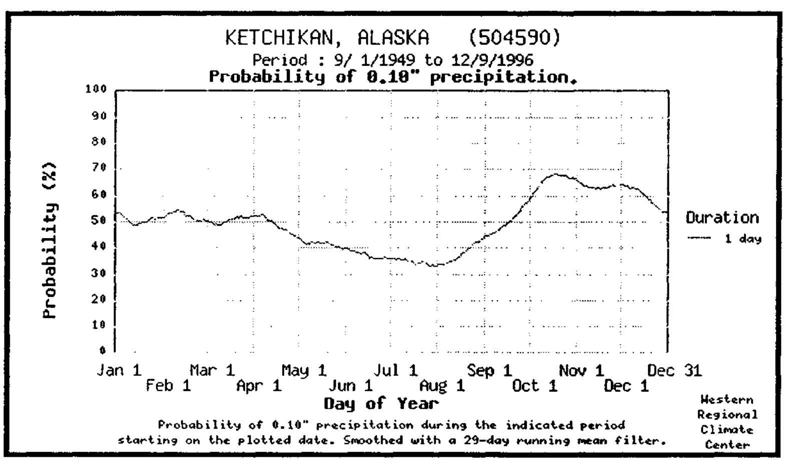


Table 1
Probability of Precipitation

	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	YEAR
MEAN NUMBER OF DAYS:													
Precipitation													
.01 inches or more	19	18	19	19	17	15	15	15	19	24	23	23	226
0.1 inches or more	15	15	15	15	13	11	11	11	15	21	19	19	179
0.5 inches or more	8	9	7	7	6	5	5	6	8	13	11	10	96
1.0 inches or more	4	5	3	4	3	2	2	4	5	8	6	6	52
Snow, Ice Pellets, Hail													
1.0 inches or more	3.9	3.3	2.3	0.6	0.0	0	0	0	0	0.1	1.5	3	14.7
32 Deg. F and below	17.1	13.5	11.7	3.9	0.3	0	0	0	0	1.6	10.2	14.6	72.7
AVERAGES													
Average Total Precipitation (in.)	12.82	13.27	10.51	11.22	9.02	7.34	7.16	10.44	13.62	22.60	16.81	15.59	150.38
Average Total Snowfall (in.)	13.6	9.2	3.3	0.3	0.1	0.0	0.0	0.0	0.0	0.1	2.3	8.5	37.4
Average Max. Temperature (F)	38.7	42.2	44.6	50.3	56.8	61.6	65.3	65.5	60.5	52.1	45.0	40.8	52.0
Average Min. Temperature (F)	27.7	31.4	32.6	36.4	41.5	46.9	51.1	51.6	47.2	40.9	34.6	31.1	39.4
RELATIVE HUMIDITY (%)													
Hour 10 (Local Time)	81	79	78	76		78	81	83	85	85	83	82	
WIND													
Mean Speed (mph)	12.3	11	11.2	9.3	9	8	8.3	9.3	12	12.4	12.6	10.6	
Prevailing Direction	ESE	SE	SE	SSE	SSE	SSE	SSE	SSE	SE	SE	ESE	ESE	
Fastest Mile-Speed(mph)	58	50	48	60	44	44	35	40	51	55	51	58	
Peak Gust													
-Direction(!!)	SE	SE	SE	SE	SE	SE	SE	E	SE	SE	SE	SE	
-Speed(mph)	63	66	67	59	55	49	39	51	55	74	71	69	

Table 2
Compiled Climate Data for Ketchikan

Tidal Datum

Tidal datum at Ketchikan, Tongass Narrows are from the NOAA Center for Operational Oceanographic Products and Services located at the following web address http://www.opsd.nos.noaa.gov/bench/ak/9450460.txt.

Tidal datum are based on the following time periods:

- LENGTH OF SERIES = 19 YEARS
- TIME PERIOD = 1960-1978
- TIDAL EPOCH = 1960-1978

Elevations of tidal datum referred to mean lower low water (MLLW) are as follows:

- HIGHEST OBSERVED WATER LEVEL (12/02/1967) = 21.27 FEET
- MEAN HIGHER HIGH WATER (MHHW) = 15.38 FEET
- MEAN HIGH WATER (MHW) = 14.50 FEET
- MEAN TIDE LEVEL (MTL) = 8.03 FEET
- MEAN LOW WATER (MLW) = 1.55 FEET
- MEAN LOWER LOW WATER (MLLW) = 0.00 FEET
- LOWEST OBSERVED WATER LEVEL (12/30/1959) = -5.13 FEET

Section 17 REGULATION OF DRY DOCK ENCLOSURE

Permitting

Two types of foundations are possible for enclosure of floating dry docks; pile supported foundations and floating foundations where the dry dock structure is modified to support the proposed enclosure. These may be classified as an earth supported foundation or a floating foundation.

If piling, or in water construction, is selected as the foundation for dry dock enclosure, regulatory involvement will follow the hierarchy required for typical waterfront construction projects. If new pilings are to be driven, the Corps of Engineers will be the lead agency for environmental review and permitting. State and local planning agencies and building officials will, in many jurisdictions, control other impacts relating to building height, location and other planning considerations. Local building codes may control design and construction standards as well as allowable occupancies, setbacks and fire prevention considerations.

In Alaska nearly all tide lands are owned by the state and the following agencies would be involved with "in water" construction. The listed agencies would review the permit application for consistency with the Alaska Coastal Management Program (ACMP).

- US Corps of Engineers
- Alaska Department of Conservation
- Alaska Department of Fish & Game
- US Fish & Wildlife Service
- National Marine Fisheries Service
- Alaska State Office of History and Archeology
- Alaska Department of Natural Resources – Tideland

Local and state building codes may regulate design review and construction inspections. Site inspections and plan reviews are conducted by the local Building Official and the state Fire Marshall.

If an enclosure were to be mounted on a buoyant foundation such as a dry dock, the regulatory review would revert to the classification agencies of the vessel. In Ketchikan however, local and state building officials have extended their jurisdiction to include marine vessels where human habitation rather than transportation is the primary purpose of the facility. This extension of authority to registered vessels resulted from precedence established for regulation of the numerous camp barges that populate Southeast Alaska. These barges are often registered marine vessels, but the presence of hotel type structures and the related safety issues have caused the State Fire Marshall to perform plan reviews and facility inspections of the hotel structures located on barges. The barges themselves remain under the jurisdiction of the US Coast Guard and American Bureau of Shipping (ABS).

Because the proposed use of the enclosed structure in the Ketchikan is an industrial activity normally associated with land based manufacturing facilities, it is anticipated that a similar regulatory regime will exist for enclosure of floating dry docks in Alaska. For the Ketchikan dry dock, the marine engineer would certify the dry dock through the Annual Safe Dock review. Plans and specifications for the dry dock enclosure would be submitted to the marine engineer responsible for the Annual Safe Dock review

The Occupational Health and Safety Administration regulates employee health and safety. Potential impacts of enclosure on worker exposure are discussed below

State & Local Building Code Review

General Design Conditions

Given the physical operating conditions of the Ketchikan dry dock, design objectives for enclosure of ships in Ketchikan should include:

- Protect ship repair processes from weather.
- Minimize direct costs of enclosure to ship repair processes.
- Minimize cycle time for deployment and retraction of enclosure.
- Operation of retraction and extension components in winds of up to 20 mph.
- Contain or reduce air and storm water emissions from the dry dock.

Design Requirements

Previous Reports have identified local design requirements for buildings regulated under the Uniform Building Code. They include:

- 100-mph wind with exposure factor D.
- Snow loads of 30 pounds per square foot.
- Seismic Zone 2b

To understand the regulatory requirements of state and local plan review, the author has included an analysis for local and state building codes. Ms. Linda Millard[41] of Peters and Associates performed this code analysis. The analysis was based on an enclosed footprint of 72,687 square feet with a building peak of 138 feet in height. Her analysis conforms to the Uniform Building Code, 97 Edition.

The occupancy group for the dry dock would be Group F1, which covers moderate hazard factory and industrial occupancies including the production and repair of boats.

Membrane structures are addressed in the UBC in Appendix C Chapter 31 - Division II - Membrane Structures. The construction classification for membrane structures is noted as Type V- Nonrated, and Type II - Nonrated construction for noncombustible membranes and fire resistant membranes. In addition, noncombustible membranes used exclusively as roof and located more than 25 ft. above any floor, balcony, or gallery, are deemed to comply with the roof construction requirements for Type I and Type II fire-resistant construction.

Within these parameters and with a site that is surrounded by public ways or yards at least 60 feet in width, the structure could be designed and permitted per current codes. Type II - Fire Rated construction would limit the structure to a height of 160 feet. The area for a structure of this type of construction would be limited to 39,900 sf, which could be doubled to 79,800 sf if there is a separation on three or more sides. The addition of an automatic sprinkler system would allow construction of the proposed structure with unlimited area. The Ketchikan dry dock has adequate separation on three sides.

In addition, the Uniform Building Code makes several exceptions to height and area limitations for one-story structures used as aircraft hangers. It might be argued that these requirements might also apply to enclosures on a dry dock. Both of these uses are defined as Special Purpose Industrial Occupancy by NFPA 101 Life Safety Code, 1997 Edition, Chapter 28 - Industrial Occupancy, which recognizes buildings designed for and suitable for only particular types of operations, characterized by a relatively low density of employee population, with much of the area occupied by machinery or equipment.

Federal Regulations and Potential Impacts

The section was provided Mr. Dana Austin[42] and was developed as Deliverable III of this project.

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[41]Ms. Linda Millard, Steve Peters & Associates, Ketchikan Alaska. Phone (907) 225-7133

[42] Mr. Dana Austinana M. Austin Environmental Consulting, Inc., Dana M. Austin Environmental Consulting, Inc. 11111-2A San Jose Blvd., Suite 312, Jacksonville, FL 32223 Phone: (904) 287-1034

Potential Aspects And Impacts

The goal of this section is to describe the potential health, safety, and environmental aspects and impacts associated with the enclosure of dry docks. It is important to understand the potential aspects and impacts associated with dry dock enclosure so that we determine regulatory requirements that could potentially apply.

For the purposes of this paper, the definition of environmental aspects has been taken from ISO 14001:1996, and includes the consideration of the element of an enclosed dry dock's activities, products, or services that can interact with the environment. Environmental impacts can be defined as any change to the environment, whether positive or negative, in whole or in part, resulting from enclosed dry dock activities, products, or services. For example, boilers have environmental aspects and impacts associated with them that include the use of diesel fuel, which generates air emissions, blow-down, which results in discharges, and potential permitting requirements.

Aspects

Major shipyard activities include abrasive blasting and surface coating, machinery rebuilding and installation, systems refurbishing, maintenance, and installation, new equipment installation, propeller and rudder changes, alignment, and repairs, and lastly, structural modification to the ship. (NSRP, 1993) Other aspects include burning, cutting, brazing, and welding.

Chemicals used for surface preparation include caustic solutions, nitric acid, sulfuric acid, and rust preventative, among others. (NSRP, 1993) Other hazardous materials used include paints, lubricants, fuels, abrasives, solvents, and adhesives.

Examples of utilities supplied by the docking facilities are fresh water, sea water, boilers for steam, disposal receptacles for sanitary wastewater, disposal receptacles for solid waste, tanks and pumps, compressed air, power, various welding gasses, crane service, fire systems, telephone, and wastewater removal. (NSRP, 1993)

For the purposes of this paper, the above listed activities have been divided into five major categories, with impacts of each listed in Section 4.0:

1. Abrasive Blasting
2. Marine Coating Application
3. Polyester Lay-up and Repair Operations
4. Welding, Brazing, Burning, Cutting
5. Operation of Internal Combustion Engines

Please refer to Appendix C for a tabular summary of aspects associated with the enclosure of dry dock activities and the related health, safety, and environmental impacts and potentially applicable legal requirements.

Impacts

For the purposes of this paper, impacts from the aspects identified above, are defined as any change to the environment, whether positive or negative, in whole or in part, resulting from the enclosure of dry dock activities. For example, solid waste generation is an environmental impact associated with dry dock activities.

Waste and pollutants from activities listed in the previous section include spent abrasives, particulates, fouling organisms, adhesives, solvents, detergents, waste acids, grease and oil residue from tank cleaning, and spent abrasive blast media. (NSRP, 1993)

Waste from painting activities include excess paint and paint-related waste, VOCs, HAPs, VOHAPs, trichloroethane, n-butyl alcohol, benzene, and xylene, which are all flammable and poisonous materials.

> *"VOCs accounted for about 86 percent of the shipbuilding and repair industry's reported TRI releases. The remainder of the releases were primarily metal-bearing wastes. Xylene's, n-butyl alcohol, toluene, methyl ethyl ketone, and methyl isobutyl ketone account for about 65 percent of the industry's reported releases."* (US EPA, 1997)

Particulate emissions from abrasive blasting operations include PM_{10}, metals in paints being removed including lead, copper, nickel, zinc, and tri-butyl tin (TBT). One main problem for all shipyards is fine, inhalable dust produced from shipyard building and repair operations. Instead of being released directly into the air, as is the case in current operations, in an enclosed dry dock, these wastes become potential indoor hazards.

While ships are in dry dock, they are currently ventilated at the ends and top, with emissions released directly to the air. Wastewater is typically discharged through the dock sally ports, which are openings in the sidewalls of the dry dock.

The shipbuilding and repair industry emits air pollutants on a continual basis. The graph below shows total amounts for 6 main pollutants in tons/year. Note PM_{10} refers to total suspended particles less than 10 microns in size, and PT refers to total particulate matter.

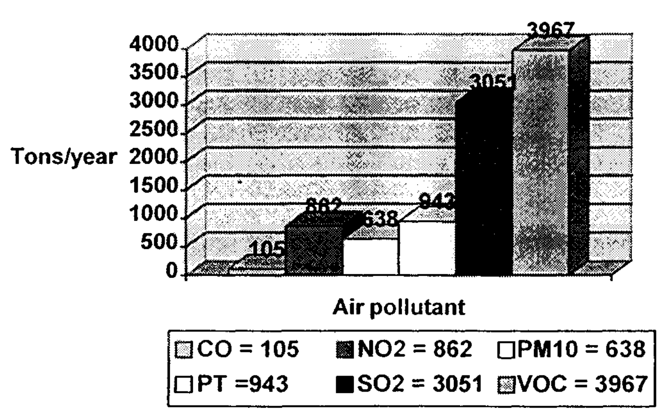

Table 1: Air Contaminants in tons/year (EPA, 1997)

As mentioned earlier, the largest concern when enclosing dry docks is indoor air quality. Therefore, attention must be paid to Clean Air Act requirements. As is evident in Table 1, the shipbuilding and repair industry in total emits 9566 tons/year of air contaminants.

> *" The Act provides that any stationary source having the "potential to emit" more than 10 tons per year of any of the listed substances, or 25 tons per year of any combination of substances, is considered a major source and is subject to regulation under the major source program." (Government Institutes, Inc.1997)*

Ventilation is a major concern. All fugitive air emissions will now be enclosed inside the dry dock enclosure, and therefore subject to the indoor air quality guidelines of OSHA. These will be addressed in the next section. Please also refer to Appendix C for a summary of aspects; health, safety, and environmental impacts; and legal requirements.

Additional Considerations

Several additional considerations will need to be addressed after the enclosure of dry docks. Some items listed below are not new requirements for dry dock activities that will need to be met after enclosure, but are still worth mentioning to ensure compliance.

Noise pollution may be a new consideration with the enclosure of dry dock activities, if the enclosure causes the sound level in the dry dock to increase above acceptable levels. Title 29 of the Code of Federal Regulations, Volume 5, Section 1910.95 details occupational noise exposures. For example, during an 8 hour duration, the decibels must not exceed 90 dBA, when measured on the A scale of a standard sound level meter at slow response. If sound levels exceed this level, "protection against the effects of noise exposure shall be provided." (29 CFR, Part 1910.95)

The need for ventilation has been mentioned many times in this paper. It would be worth exploring the possibility of running all air emissions through the sally ports directly to the outside for venting. For example, fumes from the interior combustion engines and vapor recovery equipment used for working on oil tankers and barges could be vented in this way.

In addition, passive venting with particulate controls should be considered. Examples include open or mesh panels with fogging nozzles for dust control wherein small droplet size combine with small particles increasing weight and reducing or eliminating migration.

Hazardous waste must be stored in accordance with 40 CFR 262.34 requirements. It will be important for the yard to modify its contingency plan to reflect the enclosed dry dock operations. It may also make sense to establish a satellite accumulation area within the dry dock area to appropriately manage the hazardous wastes generated in the area (40 CFR 262.34). These wastes can then eventually be transferred to the yard's permanent hazardous waste storage area to await final disposition. One issue to consider is whether the entire enclosed dry dock area could be managed as a satellite accumulation area. This issue could be explored further to ascertain benefits and disadvantages associated with the same. It will be important to remember however, that the satellite accumulation area must be inspected weekly.

Debris, likely to be generated during dry dock activities, must be managed in accordance with 40 CFR 268.2. It is defined as a solid material exceeding a 60 mm particle size that is intended for disposal and that is a manufactured object, plant or animal matter, or natural geologic material. The following types of materials however are not considered debris:

Any material for which a specific treatment standard is provided in Subpart D, 40 CFR 268, namely lead acid batteries, cadmium batteries, and radioactive lead solids;

Process residuals such as residues from the treatment of waste, wastewater, sludges, or air emission residues; and

Intact containers of hazardous waste that are not ruptured and retain at least 75 percent of their original volume.

A container is any portable device in which a material is stored, transported, treated, disposed of, or otherwise handled (40 CFR 260.10).

Debris that contains a hazardous waste listed in Subpart D, 40 CFR 261, or that exhibits a characteristic of hazardous waste identified in Subpart C, 40 CFR 261 (40 CFR 268.2).

The Uniform Fire Code (UFC) designates requirements for fire prevention and fire protection in the U.S. for structures, depending largely upon what type of structure is being considered. An enclosed dry dock may be defined in several ways, based upon how much area is enclosed and how long the enclosure is closed. For example, "Temporary Structure" is defined in the 1994 UFC as "an enclosure or shelter constructed of materials as described in Article 32 and erected for a period of less than 180 days." If a dry dock is enclosed for more than 180 days, it could be regulated as a permanent structure.

UFC of 1994 also lists building requirements for, among others, the number of exits, stairways, fire escapes, sprinkler systems, storage of hazardous materials, door locks, smoke and heat removal vents, spill control, and smoke detectors for living quarters.

All welding and cutting activities would be regulated in Article 49 of the UFC. Any compressed gases would be covered under Article 74, and explosive materials under Article 77. Flammable and combustible liquids are regulated under Article 79, and Article 80 covers hazardous materials. Lastly, electrical equipment and wiring requirements are covered under Article 85 of the UFC of 1994.

The EPA has established regulations for asbestos emissions during renovation and demolition projects. Should any work take place during dry dock activities that could result in asbestos generation, these requirements must be reviewed to assess the amount of regulated asbestos containing material (RACM) that is present on the ship. There are notification and emission requirements for any demolition or renovation activities where the amount of RACM disturbed is 260 linear feet on pipes, at least 160 square feet on other facility/ship components, or at least 35 cubic feet from facility components where the area could not be previously measured (40 CFR 61.145 and 146).

Lastly, Section 6 of TSCA requires the EPA to specifically regulate the manufacturing, use and disposal of polychlorinated biphenyl compounds (PCBs). Regulatory issues for enclosed dry dock operations would arise in the event of the use, storage or removal of electric equipment such as transformers and capacitors on hydraulic equipment. Record keeping and inspection requirements are found in 40 CFR 761.

Conclusions

In general, we have not identified any one particular regulatory requirement that would appear to preclude the enclosure of dry dock activities. Repair and maintenance activities in the enclosures must comply with the regulatory requirements with which shipyards already have experience complying. The requirements of most significance are those regulating air emissions. Because emissions will now be captured within the dry dock enclosure, steps must be taken to control and mitigate the emissions to prevent harmful exposures both to the ship inhabitants and to workers.

Investments may have to be made in the area of pollution control equipment and ventilation.

Air monitoring may have to occur on a 24-hour basis.

Some activities may have to be performed in isolation, where there is some type of barrier between the activity and the employee.

Substitution of toxic materials with less toxic ones may have to occur.

Additional attention to personal protective equipment may also be necessary due to the increased potential risk of exposure to air contaminants.

Passive ventilation procedures may provide cost effective control of internal atmosphere.

The activities could require permitting, but again, this should be feasible and reasonable to accomplish. Indirect advantages to enclosing dry docks may include safer working conditions, a decrease in spills, and closer attention to handling, use and storage of hazardous materials to reduce emergency situations.

Employing retraction systems that use tension and relaxation as operating principles will enable the system to use passive atmospheric controls as a means of limiting employee exposure to dangerous concentrations of dust and vapors resulting from surface preparation and coatings operations. The attendant reduction in wind velocities will aid in controlling airborne releases of material from the dry dock. Dry docks located in areas with regulations prohibiting atmospheric discharge of pollutants will have an opportunity to install more active control systems, but due to the scale or volume of enclosure new control strategies will no doubt need to be devised. One example of a more passive control system for airborne particulates would be the use of open netting and misting nozzles in conjunction with the self venting capacity of the structure. Fabric panels in the structure could be opened to introduce a flow of air toward a leeward opening. Solid panels could be replaced with an open mesh material capable of resisting prestress and applied loads but capable of allowing air to flow through at a reduced velocity. Airborne particulates could be captured at a leeward opening using agglomerative dust suppression techniques such as those developed by the Raring Corporation.

Recommendations

The advancement of new technology which would result in superior environmental protection should not be impeded by regulatory barriers which limit applicability or increase costs beyond practical implementation. The shipbuilding and repair industry should seek regulatory relief when industry advances technology to control previously uncontrolled emissions or discharges. Permits may be required but regulatory reform should be aimed at reducing regulatory requirements such that industry is not penalized for advancing environmental containment or control.

Section 18 PROPOSED ENCLOSURE SCHEMES

The various schemes being proposed for final feasibility studies for enclosure of the Ketchikan dry dock range from traditional industrial architecture to innovative forms of tensile construction specifically developed for use in floating dry docks; or in terms of technical challenge, from the simple to complex.

Crane access is needed to transfer equipment, materials and supplies from the shore to the vessel. This means the dry dock enclosure must have deployable sections. Overhead cranes are often present in structures enclosing graving docks and marine railways. This type of operation may be a viable option for both pile supported structures and possibly for some enclosures that are supported on a floating dry dock. However, the added height requirement of overhead cranes and upward movement of the vertical center of gravity may make overhead cranes in floating dry docks impractical. This needs study.

From an operational perspective the most cost-effective enclosure for the Ketchikan dry dock would provide:

- full enclosure of the M/V Kennicott
- support an internal bridge crane system
- provide pier crane transfer of material to and from dry dock.

The following enclosure schemes are arranged in order of their complexity beginning with the simplest and ending with the most complex.

- Conventional nesting steel building founded on marine structures.

- Nesting fabric buildings, horizontal retraction, founded on the dry dock.
- Horizontally compressible fabric structures.
- Vertical retraction systems with semi-rigid membrane.
- Vertical Retraction Systems with flexible membrane systems.
- Tensile construction mounted on the vessel.

An inverse relationship between the cost of installation and the cost of operation exists across the range structures being proposed for dry dock enclosure. Enclosure systems that resemble traditional architecture have higher front-end installation costs but lower operational costs over the service life of the enclosure. The more complex tensile systems that deviate from traditional architecture may be capable of reducing front-end costs but could have higher operational costs over the enclosure's service life. The final selection of the appropriate enclosure strategy will be based on both economic and engineering principles that apply to any particular shipyard and dry dock.

Conventional Steel Building Founded on Piling

In order to provide a base line cost from which to compare other enclosure concepts that are founded on floating dry docks, the author included an evaluation of a conventional industrial building that is supported on a pile foundation. This is similar to structures currently enclosing graving docks and marine railways around the world. The drawing below shows the dimensions required for this type construction enclosing the Ketchikan floating dry dock. Crane access is provided by operating horizontally nesting rail mounted building sections to provide openings. The truss depths are estimated at 8 feet. Foundation requirements for this scheme are met by using conventional marine piling structures with horizontal bridging using large section box beams to reduce underwater constructions.

Considerable costs will be dedicated to the foundation and for this type construction. The nesting truss sections depth is approximately 8 feet for each leg requiring a 16-foot wide foundation to support the rail system. This proposal is illustrated in Figure 9 and 10 below.

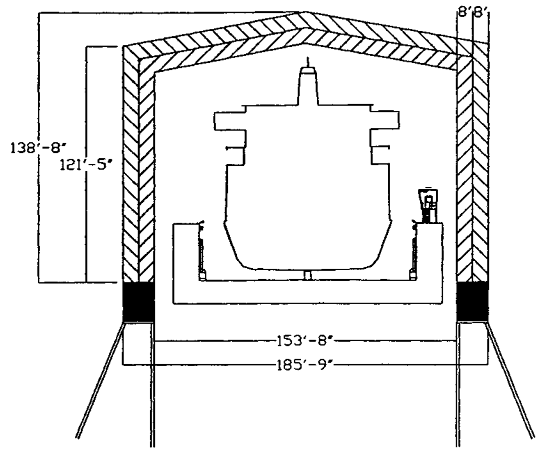

Figure 9
Section View of Conventional Steel Building Founded on Pile

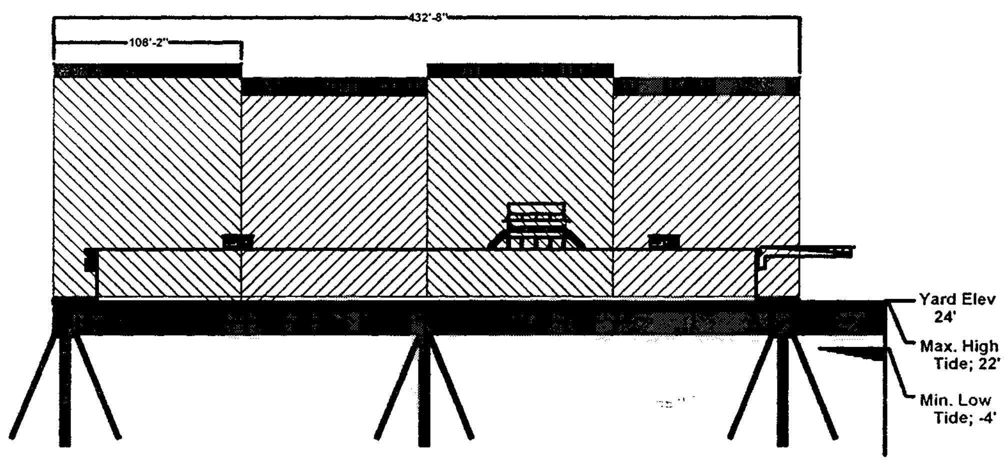

Figure 10
Outboard View of Conventional Steel Building on Piling

Steven Peters and Associates[43] evaluated the proposed enclosure shown in Figures 9 and 10. Table 3 shows the estimated range of costs to enclose the facility using conventional steel construction.

With a cost between \$3 million and \$4 million dollars, the foundation system alone becomes a major project for any shipyard. The estimated cost of this type of structure will be between \$14 million and \$20 million.

[43] Interviews with Mr. Steve Peters, Steve Peters & Associates, Ketchikan Alaska. Phone (907) 225-7133

High first costs for a full enclosure using conventional steel construction provides the basis for arguing those alternative strategies should be examined.

Nesting Steel Building on Piling						
Item	unit	quantity		unit cost	total/$	
Pile Foundation						
Piling	tons	400	700	3,500	1,400,000	2,450,000
Caps/Beams/Connections	tons	250	400	5,000	1,250,000	2,000,000
Subtotal					2,650,000	4,450,000
Sectional Steel Building						
Structural Steel	tons	1660	2200	4,800	7,968,000	10,560,000
Rail & Wheel Assembly	Est	1	1		1,000,000	1,500,000
Doors One End	tons	33	42	25,000	825,000	1,050,000
Remove Wing Wall Crane	1			250,000	250,000	250,000
Subtotal		2344	3343		**$12,693,000**	**$17,810,000**
Contingency 15%					$1,903,950	$2,671,500
Total					$14,596,950	$20,481,500

Table 3
Cost Estimate for Traditional Steel Building Mounted on Piling

Fabric Enclosures on Buoyant Foundations

Having established a baseline cost for earth based foundations of between $14 and $20 million, the remaining concepts presented in this report will focus on buoyant foundations using the floating dry dock. Self-weight of most steel buildings are in excess of the amount typically tolerated for stability of most floating dry docks. Adding live loads to the dead loads of typical steel building will likely produce extremely unstable conditions for most dry docks. It is in this application then, that the properties of tensile construction are fully appreciated for their unique properties.

The curved shape of tensile systems facilitates use of efficient and strong arches and paraboloids. Further, curved shapes reduce the enclosed volume and improve the aerodynamic so wind and snow loads are reduced. That is, the snow will shed.

The location of wing wall mounted cranes, ship alignment systems, and other wing wall mounted equipment will influence the mounting points for the enclosure foundation. The wide and tall ship section of the M/V Kennicott, used in the Ketchikan worst case scenario requires the enclosure system be mounted on the top or outside of the wing walls. Crane service for the Ketchikan dry dock would be relocated to the adjacent pier for this large, dock mounted enclosure.

Nested tensile structures consist of rail mounted tensile sections of varying sizes or radii that retract and extend in a "telescoping " fashion to accommodate crane access or oversized vessels. A positive aspect of this scheme is the ability to maintain pre-tension on the membrane during "operation" of the structure. The ability to maintain tension in the system becomes critical as the membrane sections increase in size. The potential for damage to the membrane or even entire system is greatest when the pre-tension is removed to accommodate the retraction or extension of fabric panels. By maintaining tension in the nesting sections, it may be possible to operate the system at higher wind speeds.

Frame Supported Fabric Construction

There are a number of manufacturers that supply large clear span, frame supported structures. Figures 11 and 12 were provided to several fabric building manufactures to obtain preliminary cost estimates for construction of an enclosure for the Ketchikan dry dock. The costs presented here should be considered approximate. Actual costs may be different. Accurate costs should be based on a final design of the proposed structure.

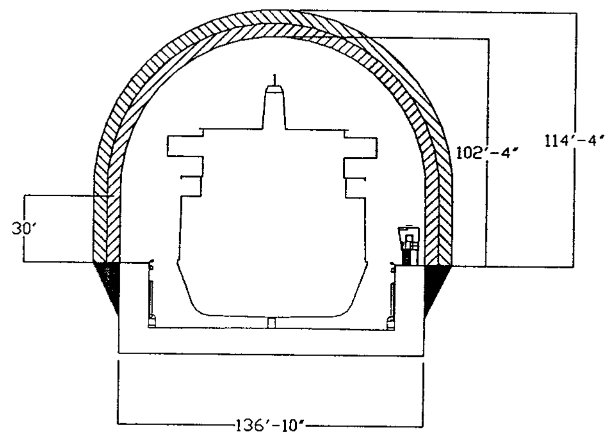

Figure 11
Section View of Sample Enclosure Concept

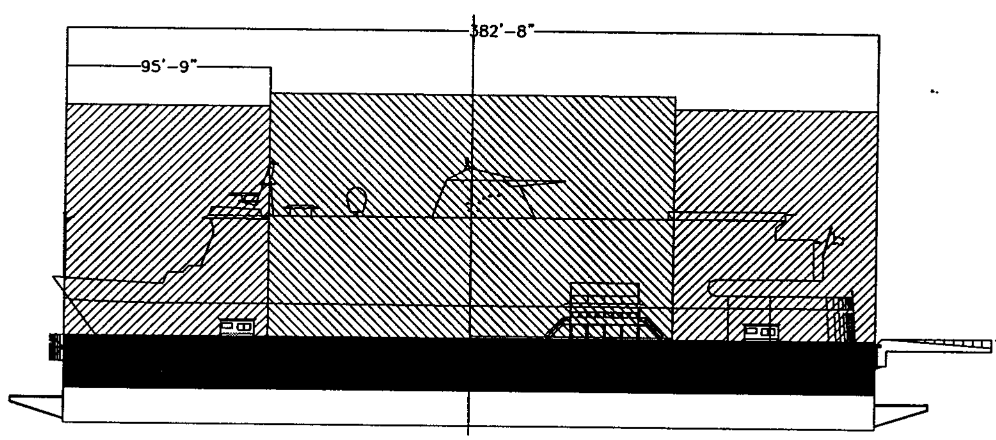

Figure 12
Outboard View of Sample Concept

Mr. Sid Morrell of Satellite Shelters/Rubb Buildings West, Inc.[44] has provided preliminary pricing for a track mounted Rubb building. The building would employ a horizontal nesting scheme on a fixed membrane structure. Mr. Morell's preliminary quotation is based on providing four 96-foot long nesting enclosures with a total surface area of 114,000 square feet at approximately $16.20 per square foot. The structure will weigh about 9 pounds per square foot of surface area or 513 tons. The building material cost then, is approximately $1,846,800. Installation costs are estimated at approximately $5.00 per square foot or $570,000 excluding crane service during assembly. Approximately 1,600 lineal feet of track will be required. The tracks weigh about 35 tons with a material cost of approximately $60 per lineal foot totaling about $100,000 material cost.

For end wall treatment, Mr. Morell provides several options. Option 1 is a panelized system that would require installation for removal at about $14 per square foot. Option 2 is a sliding door at about $20 per square foot. Without a full description of the details of the sliding door option, the author recommends a panelized system for the bow of the dry dock and the sliding door option for the stern. The stern is where vessels transit the sill of the dry dock. The area of each end wall is about 145,000 square feet.

The estimated cost to install a nested Rubb building on the Ketchikan Dry Dock #1 is approximately $5.0 million as presented in Table 4.

Rubb Building Item	unit	quantity	unit cost	total/$
Remove Wing Wall Crane	ea	1	250,000.00	250,000
Wing Wall Foundation				
Structural Steel	tons	190	4,400	836,000
Rubb Building				
Basic Material	tons	385	4,796.88	1,846,799
Install	sq.ft.	114,000	5.00	570,000
Track $60, install @ $60	lin.ft.	1,600	120.00	192,000
Section end wall	sq.ft.	15,000	14.00	210,000
Sliding Door	sq.ft.	15,000	20.00	300,000
Install 2 ends	sq.ft.	30,000	5.00	150,000
			Subtotal	**4,354,799**
Contingency 15%				653,220
			Total	**$5,008,019**

Table 4

Figure 13 provides a cut away view of a typical Rubb building. This figure shows the galvanized steel frame supporting a fabric membrane.

[44] Mr. Sid Morrell of Satellite Shelters/Rubb Buildings West, Inc, 151 Seton Street, Port Townsend, WA 98368, Telephone: (206) 379-9718

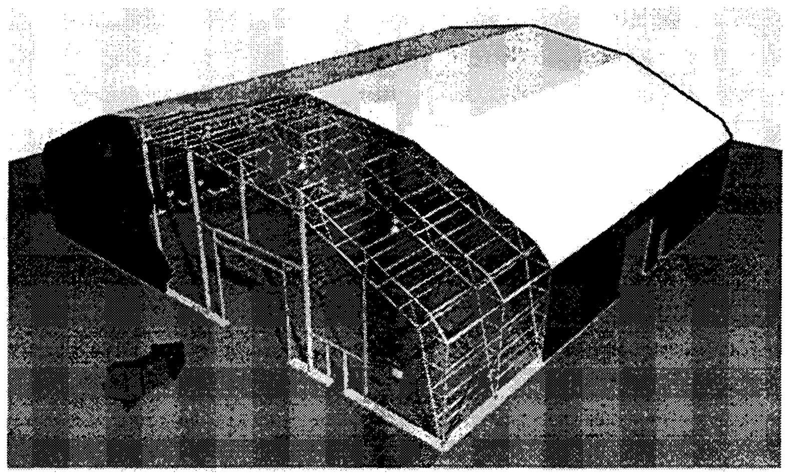

Figure 13: Typical Rubb Building

Mr. Morell has estimated that truss depth will be about 2 meters and would be constructed of 6" x 6" x 3/8" square tube for the main chords. These estimates are based on 100 mph winds and 30 pounds per square foot snow load. All fabricated steel are hot dip galvanized. Galvanization meets ASTM A123 requirements. The fabric membrane is estimated to have a minimum weight of 28 ounces and will be a PVC coated polyester. If required, the shape can be rounded or arched profiles if required.

The author requested estimates from other manufacturer's of similar systems. The estimates that were provided by the responder's illustrate that the costs present above are appropriate for this type of facility. Mr. Morell provided a detailed estimate in response to sample drawings and specifications. Thus, the cost data reported herein are those provided by Mr. Morell.

Reduce Size of Enclosure

Figure 14 depicts a typical fabric building sized to accommodate vessels approximately 75% of the height requirement of the M/V Kennicott.

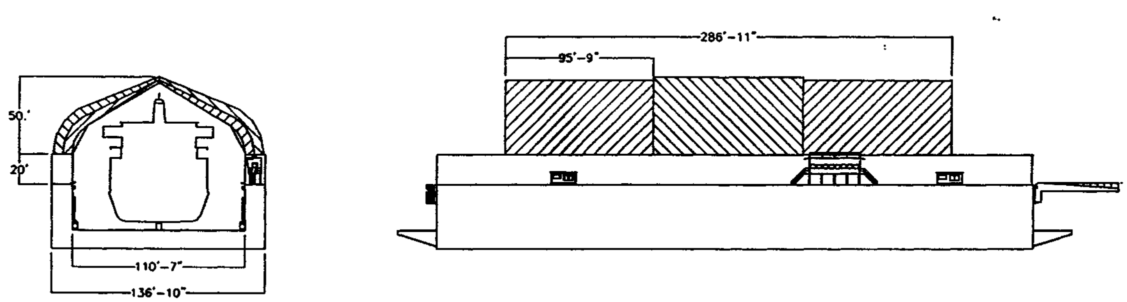

Figure 14

A smaller enclosure covering some portion of the dry dock's service fleet may yield a greater net benefit/cost ratio. In this latter case the enclosure would need to be capable of being removed entirely or positioned in a manner that could accommodate larger vessels.

Two methods may be feasible for accommodating oversize vessels when an undersized, fixed configuration dry dock enclosure is planned. The enclosure could be sectionalized for crane removal and upland storage or transferred by rail to a pile mounted rail system for over water storage. A major drawback to this approach is the general lack of open space in shipyards that can be dedicated for storage and the high cost of construction in water foundations.

Table 5 show an estimated cost for this reduced size enclosure of about $3.0 million Table 5 is based on Mr. Morrell's unit (ton) cost enclosure sized to fit the M/V Kennicott. No allowance was made for reduced structural requirements resulting from the significantly lower profile.

Reduced Size Rubb Building

	Item	unit	quantity	unit cost	total/$
Remove Wing Wall Crane		ea	1	250,000.00	250,000
Wing Wall Extension					
	Structural Steel	tons	125	4400	550000
	Fabric Membrane	sq.ft.	15,300	10	153000
Rubb Building					
	Basic Material	tons	227	4,796.88	1,088,892
	Install	sq.ft.	50,500	5.00	252,500
	Track	lin.ft.	1,600	120.00	192,000
	Section end wall	sq.ft.	8,500	14.00	119,000
	Sliding Door	sq.ft.	8,500	20.00	170,000
	Install 2 ends	sq.ft.	17,000	5.00	85,000
				Subtotal	**2,860,392**
Contingency 15%					429,059
				Total	**$3,289,451**

Table 5

Compressible Structures

Compressible tensile structures are characterized by rail mounted rigid frames that operate "accordion" fashion during extension and retraction. Fabric membranes are connected to the rigid frames. The membrane is under tension when the structure is fully deployed. When the system is retracted or compressed the membrane is relaxed and the pretension is removed hanging slack between the rigid frames. CMR Environmental Energy Research & Development Inc.[45], (CMR) has developed and installed this system for retractable barge covers and a relatively small dry dock that principally services barges. Typical CMR barge covers measuring 28' x 128' weigh 5 tons or 2.8 lbs. per square foot of footprint. The largest span that CMR recommends for its current line of enclosures is 73 feet.

CMR has installed its retractable enclosure on a floating dry dock measuring 67 feet in width and 180 feet in length. Figures 15 shows the CMR enclosure mounted on a

[45] Mr. Rob Faber. CMR Environmental Energy Research & Development Inc. 31 Armstrong Ave., Ontario, Canada, L7G 4S1, Telephone (905) 873-4140

floating dry dock and Figure 16 shows the enclosure at another location in various stages of deployment.

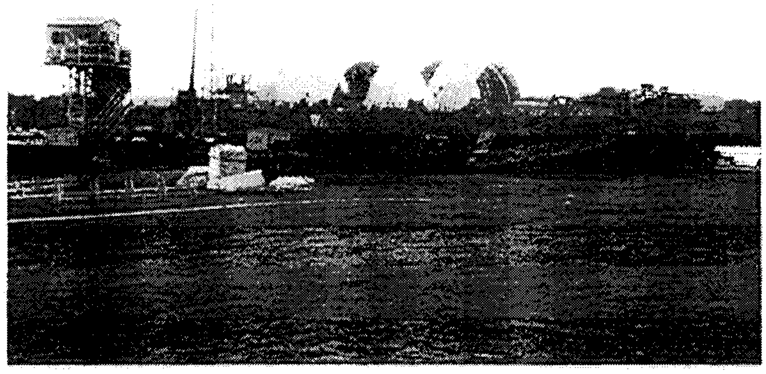

Figure 15

Figure 16

Mr. Faber believes that this structure is feasible for use on the Ketchikan dry dock. He has provided cost estimates based on a very preliminary design for this structure. The CMR retractable system would be mounted on a foundation that would extend vertically above the top of the existing wing walls. The enclosure would consist of two movable sections that could compress up to 35% of their extended length. The estimated weight is approximately 75 tons. Considerable engineering would be required to design the CMR system for the spans required by the Ketchikan dry dock.

Figures 16 through 18 were provided by Mr. Faber and represent the initial design upon which he based his preliminary estimated costs.

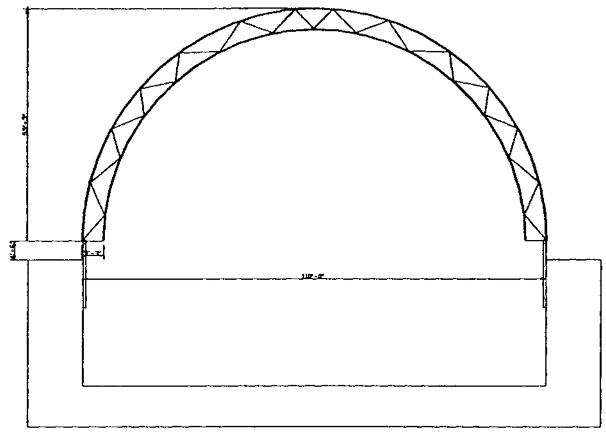

Figure 16: Section View of CMR Enclosure

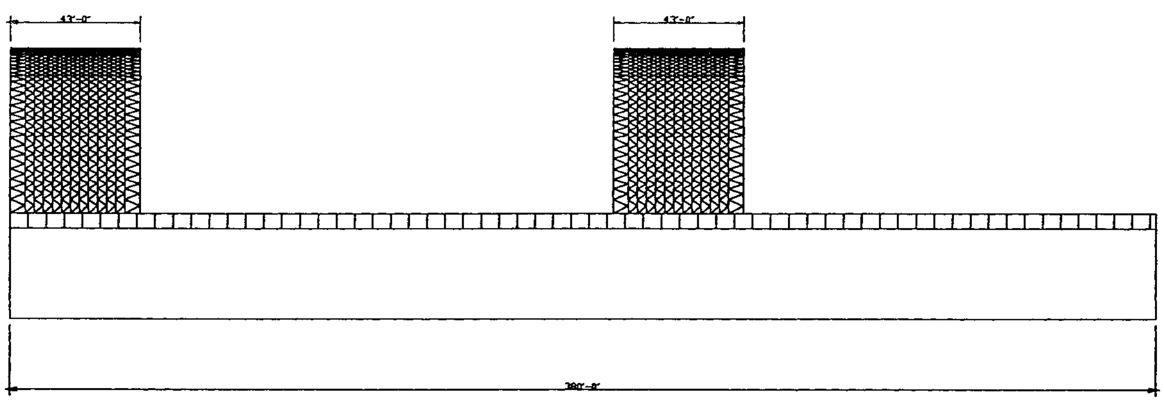

Figure 17: Outboard View of CMR Enclosure in Retracted Position

The frame widths are estimated to be 5 feet with a horizontal spacing of 15 feet center to center when the enclosure is fully extended. When fully compressed the structure would collapse into two sections each 43 feet in width

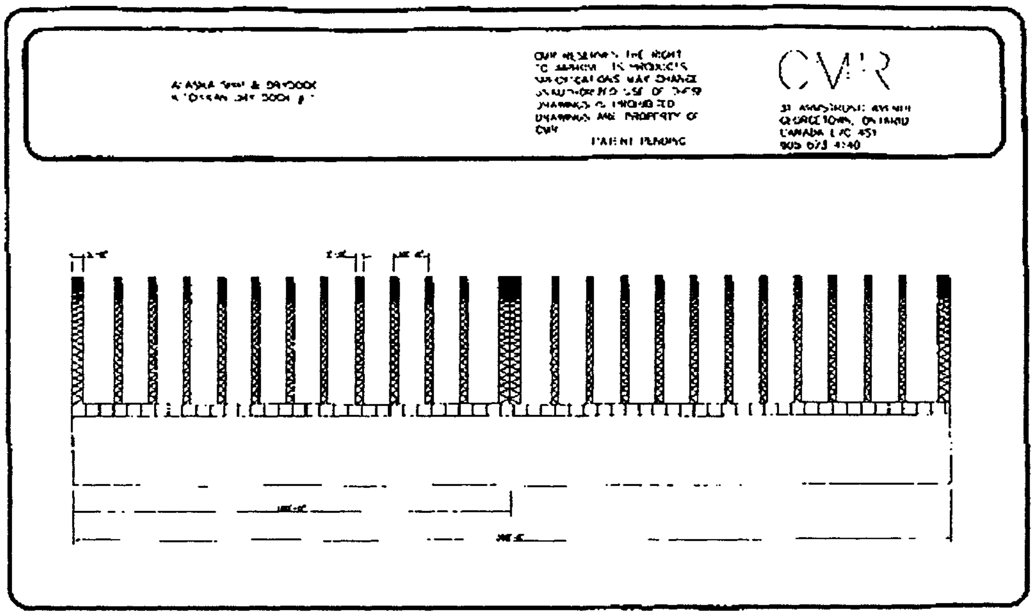

Figure 18: Outboard View of CMR Enclosure in Extended Position

Table 6 provides a very preliminary cost estimate for installation of a compressible CMR structure on the Ketchikan dry dock. The basic material cost for the CMR structure includes track steel, shoe steel, wheel steel, galvanized frames, and reinforced fabric.

CMR Retractable Building Item		unit	quantity	unit cost	total/S
Remove Wing Wall Crane		ea	1	250,000	250,000
Wing Wall Extension					
	Structural Steel	tons	190	4,400	836,000
	Fabric Membrane	sq.ft.	23,400	10	234.000
CMR Building w/ power movement					
	Basic Material	tons	75	22,667	1,700,025
	Installation	sq.ft.	65,700	5	328,500
	Section end wall	sq.ft.	8,000	14.00	112,000
	Sliding Door	sq.ft.	8,000	20.00	160,000
Engineering		ea	1	250,000	250.000
Track	Install Only	ft.	800	60	48.000
	Subtotal				**3,918,525**
	Contingency 15%				587,779
	Total				**$4,506,304**

Table 6

Issues for consideration for compressible systems on larger dry docks include:

- Methods to increasing distance between frames to reduce the number of frames
- Provision for sufficient pre-tension in the membrane
- Protection of membrane in compressed configuration.

Vertical Retraction Systems with Flexible & Semi-rigid membrane

The vertical deployment of sails mounted between booms provided an early vision of potentially viable dry dock enclosure systems. Edge control in this enclosure strategy is most easily accomplished with the bolt rope and channel assembly found on a typical sailboat. However, because the membrane panels must be deployable in moderate winds that would introduce tension and friction in bolt rope assemblies. Therefore, other means of edge control may need to be developed for large structures. A mechanical system capable of providing adequate edge control, vertical movement of the edge in a moderately loaded condition, and a method of storage for retracted membranes will need to be developed for this concept. The use of valley cables between supporting arches could provide adequate pretensioning after the panels are deployed. Pretension may also be provided with an air inflated double membrane system. If these limitations to vertical retraction can be overcome, this concept may prove to be an attractive alternative to horizontal retraction.

Replacing "flexible" fabric panels with semi-rigid, reinforced fiberglass panels (RFP) has the potential of reducing complications resulting from the requirement for pre-tension and edge control in fabric systems. RFP panels have the capability to uniformly distribute dynamic forces across the membrane while eliminating the requirement for pre-tension through corrugations of the panel. Mounting the RFP panels in multiple, parallel channels along the supporting frames provide the ability to nest individual panels vertically during retraction to provide crane access.

Because of the significant engineering required to develop efficient deployment of these vertically retracted systems, cost estimates have not been developed for this concept. Roll up fabric doors are the closest, currently available technology to what is proposed for this concept, however the manufactures of the two systems described in Deliverable IV recommend operation of their systems in the vertical plane only.

Vertical Retraction with cable tensioned fabric panels

An efficient method for applying and relaxing pretension will be required for any vertically retracted membrane. It appears, based on an extensive review of available literature, that the most promising technique for adjusting pretension is the use of a valley cable. The dotted lines in Figure 19 represent valley cables. Valley cables can be located on the outside of the enclosure or located in fabric cuffs sewn into the bottom of the panels. The advantage of tensioning with valley cables is in reducing the requirement for providing horizontal force on the main trusses supporting the system.

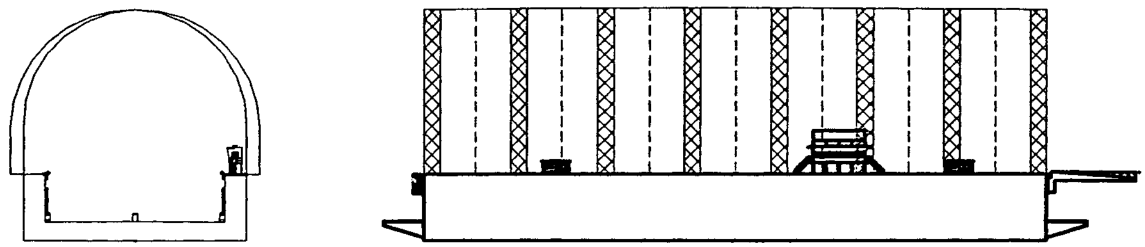

Figure19

End Wall Treatments

End wall enclosure may be one of the most problematic elements in developing a total enclosure dry dock enclosure system. Principle challenges to effectively providing end wall enclosure include:

- Arched and parabolic shapes eliminated standard roll up door applications unless rectangular door pockets are constructed at the ends.
- Rectangular door pockets increase the sail area and will require significant structural reinforcement unrelated to supporting enclosure components.

Section 11 ENCLOSURE MOUNTED TO SHIPS

Of the proposals put forth in this project the concept of developing a tensile structure that can be efficiently installed on ships is the least costly in front end development and acquisition costs. Unfortunately, the cost savings realized for development and acquisition may be offset by higher operational costs over the long term. Operational costs being the cost of deployment of the system. As a total enclosure strategy, this approach will require two enclosure methods. First, the ship mounted enclosure for topside work and, second, a dry dock mounted enclosure for side shell and hull work. The viability of a given system depends on the combination of: a) first costs; b) operational or maintenance costs; and c) life of the facility.

Aside from low acquisition costs, this enclosure strategy has several advantages over large, permanently mounted structures:

- The resulting low profile, tight fitting enclosure will reduce sail area exposed to wind loading.
- The volume of enclosed space is reduced to the maximum practical limit reducing the cost of providing environmental controls for temperature and humidity.

- Surface prep and coatings can be conducted pier side.

Pre-manufactured Frame Supported Fabric Structures

Perhaps the most straightforward approach to ship mounted enclosure would be the use of pre-fabricated structures lifted in place by crane and mounted on the vessel. Major challenges to successful adoption of this scheme include:

- Pre-fabricated enclosures are of a fixed configuration and a variety of sizes and shapes would be need to be on hand to accommodate different vessel shapes and project requirements. Enclosure for barges would have entirely different geometry than enclosures for ships.
- Storage areas would be required for the unused structures but they could be nested to reduce space requirements.
- An efficient foundation system will need to be developed for mounting the structure to the vessel. The key to efficiency with this system would be developing a foundation system that could rapidly conform to a variety of vessel configurations.. A series of universal clamps and fittings would need to be developed to reduce the variations in foundations.
- An efficient system of weather seals for the foundation will be required.

Mr. Peterson's SP-1 project identified European yards that were constructed modular frame supported fabric buildings on ships. This approach is apparently useful on ships that have large uniform shapes.

Configurable Tensile Tent

ASD has begun development of a tensile membrane system specifically designed for use on ships and described in Section 10. The first generation of the system uses off-the-shelf hardware and easily manufactured fabric panels. The ASD system will be capable of rapid deployment on a variety of ship's geometry. Section 10 described the first generation of this system developed for enclosure of weather decks on a large ferry. Additional development of deployment strategies for this system will be required for adaptation to fore and aft deck areas and barges. A separate enclosure system for ship's side shell and hull will also need to be developed.

Table 7 estimates the material costs of the first generation of ASD's ship mounted enclosure.

ASD Tensile Tent Acqusition

Item	unit	quantity	unit cost	total/$
Membrane & Extrusion	sf	6,000	4.11	24,660
Support Struts	ea	12	200.00	2,400
Anchors	ea	24	50.00	1,200
Engineering	ea	1	50,000.00	50,000
Misc. Fabrication	hrs	300	45.00	13,500
Total				$91,760

Table 7

ASD has manufactured 6,000 square feet of this prototype system. ASD's decision to move ahead with development of this system is directly attributable to knowledge acquired in conducting the research for this NSRP project. To date installation has been limited to partial erection of single panels for development purposes. Table 8 provides estimated installation costs for 6,000 square feet of the ASD's enclosure system.

ASD Tensile Tent Installation

Item	unit	quantity	unit cost	total/$
Install	hrs	80	45.00	3,600
Removal	hrs	40	45.00	1,800
Misc. Fabrication	hrs	40	45.00	1,800
Misc. Materials	ea	1	1,000.00	1,000
Total				$8,200

Table 8

The goal for this first generation of ship mounted enclosure is to identify currently available materials that can be assembled and modified into an enclosure system capable of providing weather protection in Ketchikan's climate. National Tent, Inc.[46] manufactured the sectionalized fabric panels and aluminum extrusion and ASD has manufactured the extendable masts and fittings.

Actual deployment and operation of this prototype system will provide the experience needed to gain a better understanding of the criteria for this type of system. Lessons learned during development of this first generation system will be applied toward developing a set of custom enclosure components that will be optimized for use in shipyards. Optimization of the system will be directed towards simplified structure and anchor systems leading to reduce assembly time.

A number of companies have developed containment systems for use in the general coatings industry and a few are working on systems dedicated to use in dry docks. To date, however, there does not appear to be any one system that is widely used in the shipyard industry with the exception of scaffold supported membranes. ASD's experience in using scaffold supported membranes have resulted in the following observations with respect to their use in Ketchikan:

- The membranes have a one time or limited reuse capability.
- The membranes require calm, dry weather for installation.
- Scaffolding is expensive to acquire and install.
- Scaffold frames are difficult to conform to complex ship geometry.

[46] Mr. Randy McCauley, National Tent, Inc., 32052 S. Ona Way, Molalla, OR 97038, Telephone (503) 829-5547

In House Fabrication of Weather Seals and Custom Panel's

The ASD system relies on special weather seals and custom panels to achieve weather resistance around the perimeter of the tensioned panels and penetrations of the membrane by masts, cranes or lifeboat davits. Since the lead-time for ordering these special fabrications may be very short, it may be worthwhile for a shipyard to establish in-house capability for construction of fabric assemblies. Table 9 shows the cost of purchasing equipment needed to manufacture fabric panels.

Fabric Manufacturing Equipment

Item	unit	quantity	unit cost	total/$
Radio frequency sealer	ea	1	30,000.00	30,000
Hand held hot air sealer	ea	1	500.00	500
Hot Knife	ea	1	200	200
Industrial Sewing Machine	ea	1	3000	3,000
Hand tools	all	1	500	500
Scissors				
Grommet Punch				
Mallet				
			Total	**$34,200**

Table 9

The radio frequency sealer (RF) may not be required if only small quantities of small fabrication are to be constructed. If full panels or quantities of long seams were to be performed in house, the RF sealer would be a worthwhile investment.

Forward, Aft, and Top Weather Decks of Ships and Barge Decks

The fore, aft and top decks of ships as well as open barge decks share the common complication of not having readily available overhead anchor points for supporting the ridge member of a tensile structure. In Section 10 the author described supports for the ASD system using telescoping masts mounted to the port and starboard weather decks of a ferry. Since no work was scheduled on the top deck, it was able to serve as the overhead anchor. These telescoping masts transmit compressive and uplift forces to the ship.

For larger, open decks lacking overhead mounting points a rapidly deployable frame or truss system must be developed. A suitable, off-the-shelf technology exists within the entertainment industry that may be adapted for rapid deployment of ridge members on ship mounted enclosures.

TOMCAT USA, Inc. produces a line of staging and support systems that feature lightweight foldable trusses and roof systems that appear to have potential for use in shipyards. Figure 20 and 21 show the Tomcat triangular and heavy-duty folding trusses that can be easily transported and assembled.

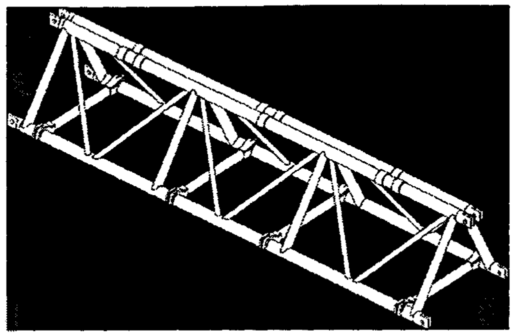

Figure 20: Tomcat©folding triangular 26" spigoted truss

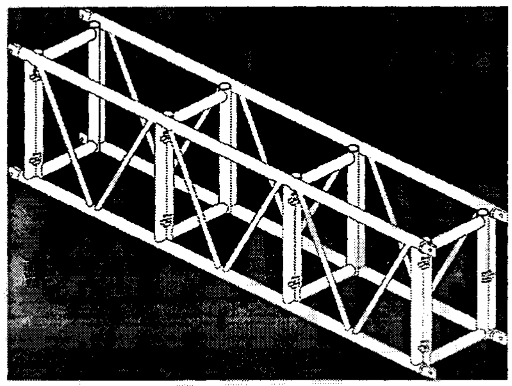

Figure 21: Tomcat©folding heavy-duty spigoted truss

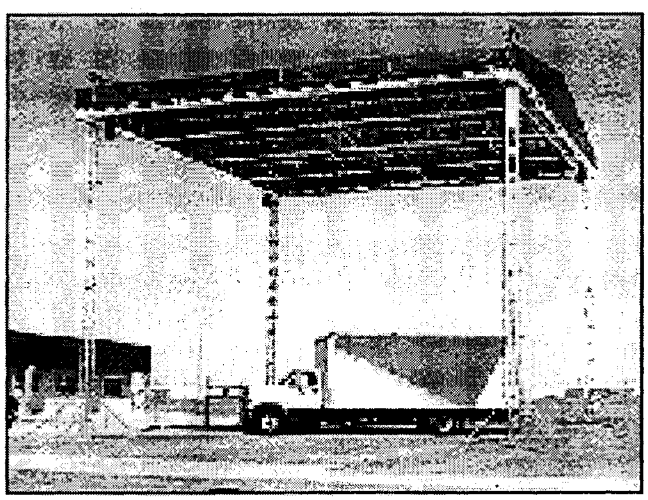

Figure 22
Tomcat©Standard 46' x 43' Roof

Figure 22 shows a TOMCAT standard roof positioned at the top of the supporting towers. Figure 23 shows a similar structure manufactured in Germany by Contact Systems[47]. This figure shows an adjustable height ground support truss system. Contact Systems provides water filled ballast tanks for anchoring the towers when no other anchor is available. The company also offers a variety of aluminum scaffold clamps and fittings that may be useful for enclosure.

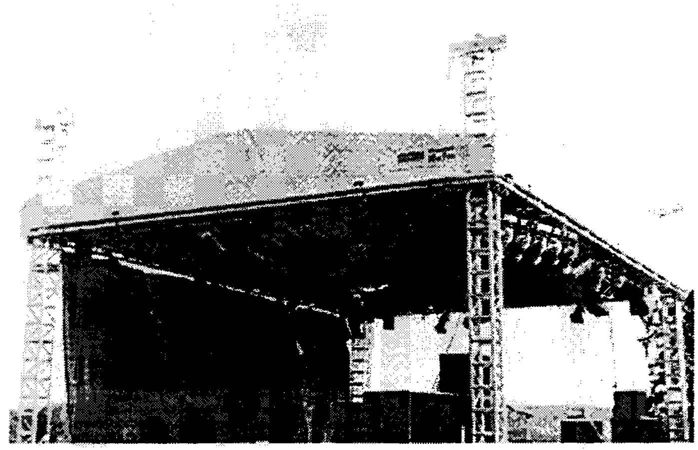

Figure 23: Contact Systems Ground Support Truss System

The author contacted Mr. Keith Bohn at Tomcat[48] to obtain the following information regarding TOMCAT's portable roof systems. Mr. Bohn provides the following regarding his company's products. *"Since TOMCAT was founded, the majority of our products are put to use in the entertainment industry. Therefore, many of our products are designed to be erected and dismantled in a short period of time. Another key element in the entertainment industry is that since the products have to move frequently from place to place, they must be easy to handle but still maintain the highest level of structural performance. Our roof structures are no different."*

"Our smallest standard roof system is one that we simply call by it's dimensions, 46' x 43'. This system is capable of a 16,000lb. uniform distributed load. It is also rated to withstand wind-speeds up to 40 MPH. The structure utilizes four aluminum towers for support, each of these extend vertically 35'. The main grid consists of aluminum trussing sections measuring 30" high and 20.5" wide and various lengths that are assembled together in a manner to provide multiple hanging locations for equipment. After the main grid structure is assembled, a canopy system is attached to the top of the system to provide weather protection over the "stage" area. The grid is then lifted into position using Columbus McKinnon 1 ton chain hoists. Once the grid reaches its top position it

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[47] Contact Systems. KarlstraBe 70, D-89547, Gerstetten, Germany. Tel: 073 23/96 20-0. Web Site http://www.contac-systems.com/homee.html

[48] Tomcat© USA, Inc. P.O. Box 550, Midland, TX 79702. Mr. Keith Bohn, Asst. U.S. Sales Manager, Phone (915) 694-7070 ext. 25. Fax (915) 689-3805. e-mail: kbohn@tomcatusa.com.

can be locked off and the motors removed from the system. A trained crew of 6 can typically get this system into position in 4 hours or less."

"As I mentioned that this is our smaller system, some of our other systems have greater levels of performance in both portable and permanent applications. These can range from clear spans over 100' between towers, to payload capacities in excess of 100,000lbs, to wind ratings of more than 100mph, to heights of over 50'. Each of our roof systems is designed and engineered by a registered professional engineer. This includes systems designed for custom applications requiring extreme levels of performance."

Based on information provided by Mr. Bohn, preliminary costs to acquire and erect a standard 46' x 43' TOMCAT system, as shown in Figure 22, is summarized in Table 10.

TOMCAT					
	Item	**unit**	**quantity**	**unit cost**	**total/$**
Modular Roof System, 46' X 43'					
	Basic Material	sq.ft.	1978	50.50	99,889
	Install	hrs	24	45.00	1,080
				Subtotal	100,969
				Contingency 15%	15,145
				Total	**$116,114**

Table 22

Specific applications of this technology for use in shipyards remain to be developed for consideration by TOMCAT USA engineers. The pricing provided here is for an existing standard TOMCAT structure and is for general information only.

Barge Decks

In Ketchikan nearly all-incoming materials and supplies and all outgoing resource commodities are hauled by tug and barge. Consequently, there exists a high demand for barge repair and maintenance at the Ketchikan shipyard. Enclosure strategies for Ketchikan must work efficiently for barges.

It is possible that a canopy system mounted to the dry dock wing walls, as discussed in other parts of this report, could be designed to provide total enclosure of barges. Constructing a clear span of 110 feet for a flat barge is much easier to accomplish than attempting the same span with over 100 feet of vertical clearance. Final benefit/cost analysis may drive the ultimate design to a full span enclosure, however, in keeping with the principle that pierside work also requires enclosure, a barge-mounted enclosure may ultimately be more useful.

Mr. Brian Peterson, as a part of his work for NSRP Project 1-96-8: Open Area Painting Overspray Containment, Deliverable 3[49], identified a United Kingdom manufacturer of a modular, temporary roof system that is integrated with its universal scaffolding system to provide relatively wide clear span trusses for weather protection and containment systems. With the permission of Mr. Peterson, the photographs in Figure 24 illustrate the HAKITEC[50] modular roof system mounted on a rail system. Mr. Peterson's report describes methods used in a graving dock to provide enclosure for a ship's side shell and hull.

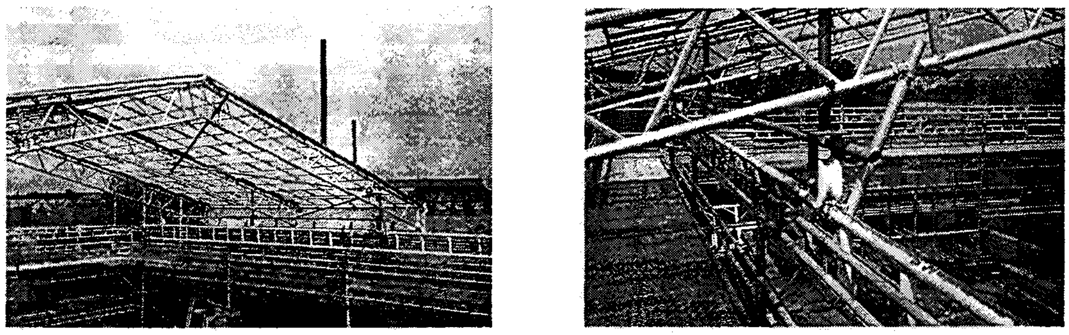

Figure 24: HAKITEC modular roof system
Ladder truss rail on left. Wheel assembly on right

So, how could a barge be enclosed? A rolling modular roof system could be set up on a barge deck to provide containment and weather protection in a sequential manner.

Mr. Bulloch of HAKI UK LTD. provided a quotation for a 100 foot by 100-foot temporary roof with four 20-ft high scaffold sidewalls. The quotation was based on 60-mph wind loads and 15 psf of snow load. The roof system would consist of aluminum roof beams (trusses) spaced at 8 foot centers with purlins at 8-foot centers. Table 11 summarizes the equipment acquisition cost and Table 12 estimates the assembly and disassembly costs.

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[49] Peterson, Brian. NSRP Project 1-96-8: Open Area Painting Overspray Containment Deliverable 3, European Containment Practices, Bremerton. 1999.

[50] HAKI UK LTD., Mr. Irving Bullock, Tame Valley Industrial Estate, Tamworth Staffs, B77 5BY. Phone 01560321879. http://www.haki.co.uk

HAKI Temporary Roof

Item	unit	quantity	unit cost	total/$
Modular Roof System, 100' x 100'				
Basic Material	sq.ft.	10000	19.91	199,100
Install	hrs		45.00	0
20' high side wall, 4 sides				0
Basic Material	sq.ft.	8,000	9.75	78,000
Install	hrs		45.00	0
Roller System				0
Rail System				
			Subtotal	**277,100**

Table 11

HAKI Temporary Roof Installation

Item	unit	quantity	unit cost	total/$
Modular Roof System, 100' x 100'				
Install	hrs	300	25.00	7,500
Dismantle	hrs	180	25.00	4,500
Ladder Beam Track & & wheels				
ASD Labor Estimate	hrs	80	25.00	2,000
20' high side wall, 4 sides				
Install	hrs	160	25.00	4,000
			Subtotal	**18,000**
Contingency 15%				2,700
			Total Installation	**$20,700**

Table 12

Penetrations in A Ship Mounted Enclosure

Ship superstructures are rarely flat open spaces that are amenable to seamless roof systems. Masts, cranes, davits, fidleys, A-frames and a host of other projections complicate enclosure aboard ships. In order to be efficient in shipyards, the proposed enclosure system must be capable of readily conforming to penetrations with weather tight seals.

Ladder trusses may be used to seal around structures that penetrate the fabric (tensile) membrane. The ladder truss provides the structure needed to transfer tensile forces of the main tensioned membrane around the penetration. A non-tensioned membrane creates a weather seal at the penetration. Figure 25 depicts a ladder truss constructed around a circular structure as is often found on ships. The horizontal members in this illustration would incorporate the edge control system selected for the particular enclosure. Non tensioned membranes could seal over the ladder truss using heat seal and wide shrink wrap tape. Another approach to connecting the weather seal to the ship's structures may be the use of adhesive backed hook and loop tape. Using Figure 25 as an example, the *hook* component of the adhesive backed tape could be applied around the circular mast. The *loop* component to the tape could be fastened to the non-tensioned weather seal.

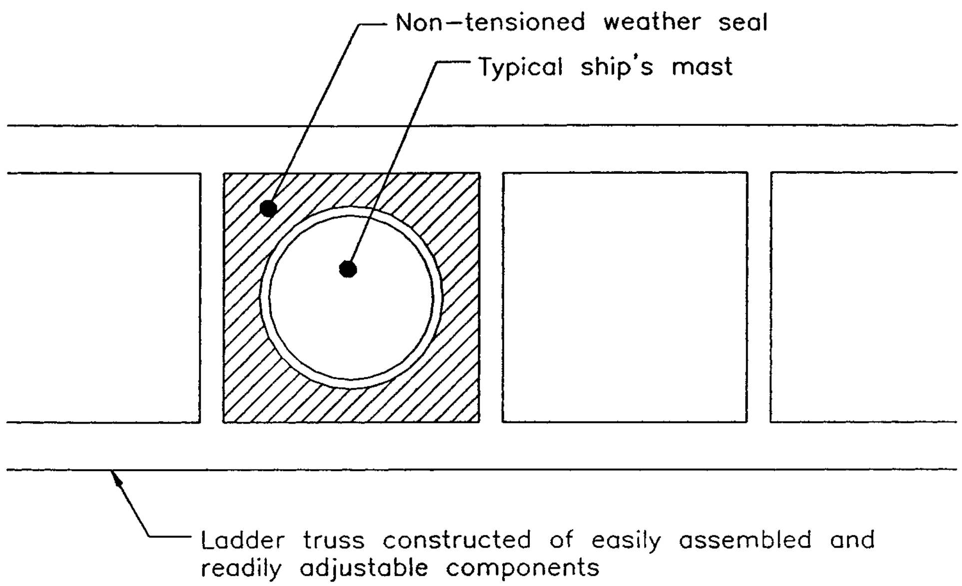

Figure 25: A ladder truss supporting a non-tensioned weather seal.

A rapidly assembled ladder truss incorporating edge control and adjustable lengths remains to be developed. Scaffold tubing and clamps are serving as the interim system for the ASD system under development.

Dry Dock to Ship

If necessary, ship mounted tensile tents offer the flexibility of maintianing enclosure of a ship's topsides throughout a vessels repair period; from pierside to dry dock and back to pierside. As was mentioned earlier, an efficient system for enclosure of the ship's side shell and hull system remains to be developed in order for a ship mounted enclosure system to be viable.

The ASD tensile tent system may be deployed from the main deck of a ship to the dry dock wing wall. However, the pressure to reduce cycle time in dry docks causes us to seek approaches that are more efficient to this enclosure condition. Because the enclosure conditions for this application are more uniform, wing wall mounted canopies may provide a more cost-effective approach.

There are two basic approaches to this enclosure condition. The first involves moveable enclosures that contain and protect operations sequentially down the length of ship. The second approach involves full enclosure of the entire length of the ship, ideally on both sides.

Rapid Deployable Systems LLC.[51] is an example of the first approach.

[51] Mr. Ray Hawes, Rapid Deployable Systems LLC, 2061 Avenue B, North Charleston SC 29405, Telephone (843) 740-1833

It is this second approach, in combination with the ASD ship mounted system, that ASD sees promise for developing cost-effective enclosure in the short term. Since the focus of enclosure in the dry dock is now to increase through put, ASD will favor enclosure strategies that will result in a maximum increase in productivity. Full enclosure of the side shell and hull will allow the surface preparation and coatings operations to complete their full cycle before crews move to the next process, i.e. all blasting can be completed before coatings application begins.

In previous reports to this project, various approaches to full enclosure of ship's hulls have been proposed. These approaches include wing wall mounted davits, booms or mechanical arms that deploy to connections at various locations on the ship to create a weather tight enclosure. The detailed mechanics of deployment, tensioning and creation of weather tight seals remain to be developed, but appear to be feasible with modern tensile construction techniques. Again, because of the range of concepts capable of providing this type of enclosure, ASD has not attempted to estimate the costs.

Catalogue

The design and assembly of a tensile dry dock enclosures will require specialized expertise in support framing, fabric shape finding and behavior, and rigging. The author has assembled a list of companies offering these specialized survives and products. The catalogue is located in Appendix C.

Section 12 SUMMARY OF BENEFITS AND BENEFIT/COST RATIO

An enclosure system must be affordable in terms of first costs. What is affordable must be evaluated for each dry dock in terms of potential savings. For example, first costs for enclosure the Ketchikan dry dock may be quite high, but the potential for increase production efficiencies and shorter dry dock cycle times may justify a relative high first cost.

First costs for non-configurable, pre-engineered fabric structures can approach $15.00 to $20.00 per square foot of foot print for large clear span enclosure as would be required for floating dry docks. Add, say $2.00 per square foot for erection and perhaps another $3.00 per square foot for mounting to the dry dock and first cost total approximately $20.00 to $25.00 per square foot for an assembled enclosure system. Width of span and height of side wall can also increase the cost, so somewhere around $25.00 to $30.00 per square foot is perhaps a realistic cost for this type of enclosure and may be cost effective for use with graving docks, marine lifts and ways or general open air coating applications. Some manufacturers use the rule of thumb that these structures are roughly half the cost of conventional building systems.

To be cost effective for use in dry docks an enclosure must:

1. be readily available on the dry dock,

2. be rapidly deployable,
3. not impede production operations, and
4. not sink exceed stability conditions of the floating dry dock.

Mr. Bent Carlson[52], the lead shipyard designer for Kaeverna Masa, Inc. estimates that moving shipbuilding to the indoors will increase productivity up to 30%. This is based on his design experience for both land-based ship building processes and ship repair halls. He has experience in climates similar to Ketchikan, Alaska. Thus, added productivity in a limited space is justification to consider an enclosure as a viable option.

Benefit /Cost Analysis

Mr. Kent Miller[53] an industrial economist has performed numerous economic studies of Alaska ship's and shipyards for the State of Alaska and local municipalities. Mr. Miller performed the following benefit/cost analysis for enclosure of the Ketchikan Dry Dock #1. The analysis uses a cost of $4.5 million for a large enclosure of the Ketchikan Dry Dock.

A summary of financial benefits of the dry dock cover is as follows:

Item	Annual Amount
Improved Utilization of Drydock	$ 240,000
Lower Overtime	189,500
Higher Labor Productivity	440,000
Reduced Rework and Recalls	175,000
Reduced Temporary Weather Protection	120,000
Total	$ 1,164,500

These benefits are based on projected 1999 gross revenue at $12 million, with $4.4 million gross labor cost.

Intangible benefits, which contribute to the foregoing, consist of improved labor morale, resulting from predictable working hours, no work on Sundays, and elimination of most work exposed to inclement weather. Other intangibles are enhancement of the yard's reputation for high quality, timely, work and improved conditions for vessel owners and crews working on or attending their vessels while in the dry dock.

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[52] Bengt Karlsson, Manager Yard Development, Kvaerner Masa-Yards, Inc. Helsinki New Shipyard, Munkkisaarenkatu 1, P.O. Box 132, FIN-00151 HELSINIKI, Finland, Tel: +358 0 194 2331

[53] Miller, Kent. Kent Miller Industrial Economist, P.O. Box 6276, Ketchikan, AK 99901, Phone (907) 225-3992

The installed cost of a dry dock cover is estimated at $4.5 million. In the approximate 15-year life of the structure prior to substantial capital replacement of its components, estimated financial benefits would total $17,467,500. Assuming these benefits accrued at a constant annual rate, based on 1999 annual gross revenue, without increase or escalation the discounted net present value (NPV) of the benefit stream would be $8,857,187, using a 10% discount rate to represent opportunity cost of invested capital. This computation indicates a benefit/cost ratio of 1.968.

The 10% discount rate represents the potential alternative earnings of invested capital under very advantageous management policies and market conditions. A reasonable alternative measure of the value of invested capital is the prospective cost of debt on the current long-term tax-exempt municipal bond market – approximately 6%. Using this discount rate, NPV of the 15-year benefit stream is $11,309,624, indicating a benefit cost ratio of 2.513. Either of these computed benefit/cost ratios is very favorable, and would justify the proposed investment.

Benefits are computed based on the following items:

Improved Utilization of Drydock

Currently, "rain days", on which work is weather-restricted, average 5 to 10 per major job, approximately 50 days per year. Recovering this productive time would increase the dry dock's utilization from approximately 253 to 303 days per year, assuming a six-day week and 10 annual holidays.

This benefit is computed as follows:

Increased Gross Revenue:	
$12,000,000 x .20 (average)	$2,400,000
Increased Net Earnings:	
@ 10%	$240,000

Lower Overtime

About 4.5% of the yard's labor cost is overtime attributable to rescheduling work to suitable weather. This could be eliminated, resulting in a cost saving of $189,500, based on the $12 million gross revenue projected for CY 1999.

Higher Productivity During Abnormal Working Hours

Labor productivity is conservatively expected to increase by approximately 10%, based on results obtained from covering dry docks in Finland and other Baltic locations. The reduction in gross labor cost at the estimated $12 million annual gross revenue is $440,000. In addition to the direct timesaving resulting from working under cover, other factors such as reduced cleanup of paint overspray and better confinement of sandblasting grit would benefit productivity.

Reduced Rework and Recalls

Currently, about $150,000 in rework is done annually to correct defects in work caused by weather while the job is in progress. An additional $25,000 in such remedial work is done after the job is finished. This could be saved with installation of the dry dock cover.

Temporary Weather Protection

At least four jobs each year require construction of a substantial temporary shelter, while most jobs require some improvised cover. This temporary weather protection would be unnecessary with the dry dock cover, resulting in annual cost savings of $120,000.

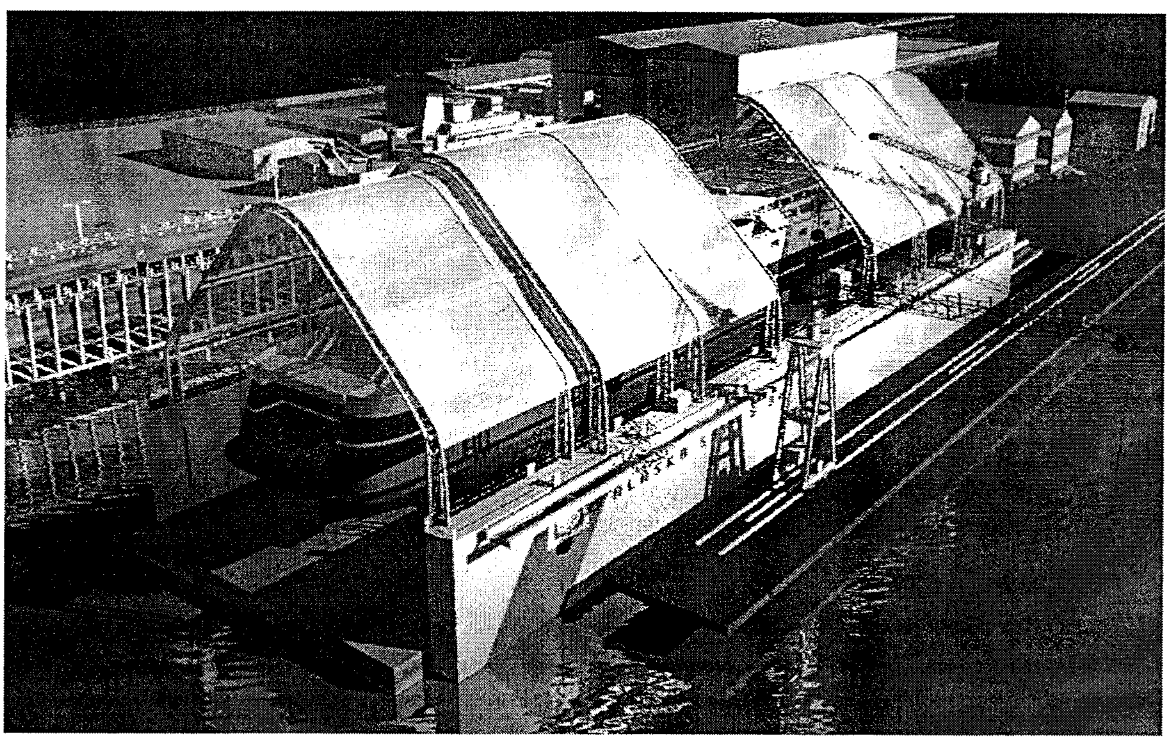
Section 13 CONCLUSION

At the beginning of this report, the author posed two questions;

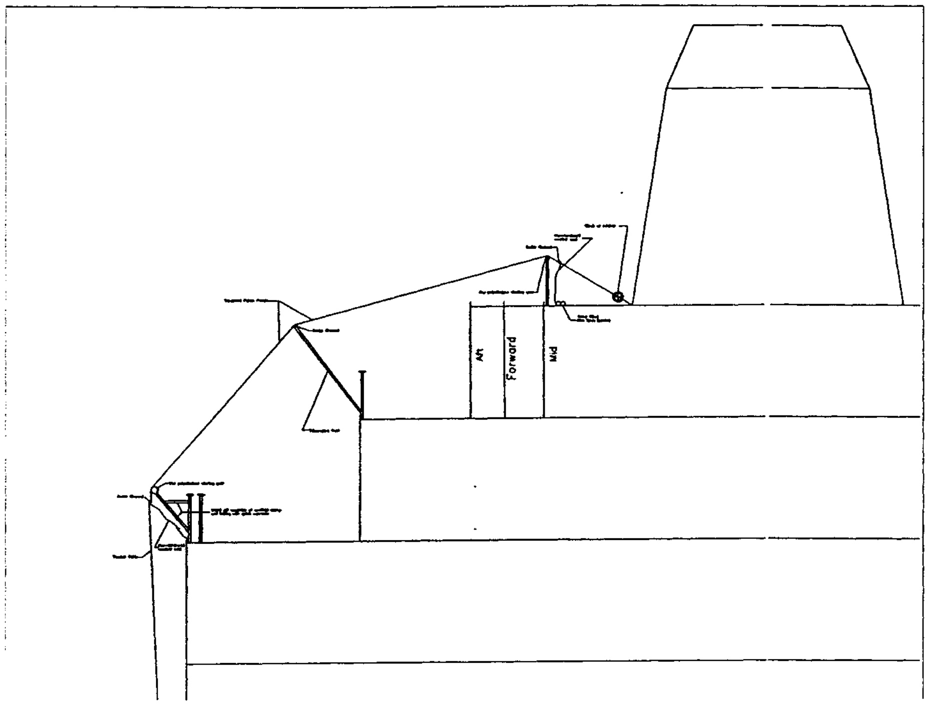
- *can current dry dock enclosure practices be improved upon* and
- *Can tensile structures be adapted to surface preparation and coatings operations in dry docks without negatively impacting other concurrent ship repair processes*?

To the first question, Alaska Ship and Drydock's experiences in using conventional enclosure systems in the extreme weather of Ketchikan have shown that innovations are needed to provide cost-effective enclosure in dry docks. To the second question, this report provides a host of enclosure concepts that may lead to the innovations required to actually construct a truly cost effective enclosure for use in dry docks. Beyond merely listing a menu of enclosure ideas, this report also attempts to provide information that will be useful to both the rigger assembling enclosures in shipyards to the architects and engineers who will be challenged to create a innovative industrial tensile structure. From this report, shipyard operators can gain an understanding of basic tensile properties and apply this knowledge to either temporary or permanent enclosure systems in their shipyards. Engineers and architects unfamiliar with shipyard operations can quickly grasp the challenges facing enclosure of ship repair processes that occur in dry docks.

Will the final solution to dry dock enclosure look something like this?



Alternatively, will it look something like this?



For Ketchikan, the final enclosure configuration will probably be much different than either one of the above concepts. These two drawings represent ends to a spectrum of potential dry dock enclosure solutions. The final selection of enclosure shape, materials, and mode of operation will incorporate the principles of tensile construction with the demands of ship repair processes to develop an innovative industrial enclosure capable of increasing profits in shipyards.

Appendix A

Glossary

Glossary

The following glossary is a compilation of definitions, many of which were provided by the Industrial Fabric Association International.

Glossary of Terms

Anisotropy	The feature of fabric wherein the physical properties and behavior are not the same in all directions.
Anticlastic	A surface with positive (Gaussian) curvature in one principal direction and negative (Gaussian) curvature in the other. A saddle shaped surface.
Auger anchors	A generic name for a family of screw-like tent anchoring devices featuring a helical projection on the shaft that provides holding power. Also referred to as a helical anchor or earth anchor.
Bail ring tent	A type of pole-supported tent where the fabric top is lifted to its peak and held in place at the top of a pre-erected center pole by means of ropes or cables and a metal ring, call a 'bail ring', after of the fabric top.
Base fabric	The uncoated fabric, also known as greige goods
Base plate	A device used at the base of a tent pole to facilitate rotating the pole up into position during the installation process. Also referred to as a mud shoe or tabernacle.
Beckets	Loops of rope laced through tent fabric sections to attach them together. Also known as Dutch lacing, laces, lace loops or lace lines.
Bias	Oriented at 45° to the warp and fill directions of the fabric.
Biaxial	Taken along two concurrent orthogonal directions, usually principal directions.
Blocks	A wooden or metal case enclosing one or more pulleys and having a hook, eye or strap by which it may be attached. When used in conjunction with tackle, it provides a mechanical advantage that is effective in raising tents - often used in the phrase 'block and tackle'.
Boss plate	Doughnut-shaped plate attached to a cable ear plate to reinforce the pinhole and allow a thinner plate.
Box beam frame-supported tent	A type of tent where an assembled framework of box beams, I-beams or truss arches supports the fabric roof and defines the shape of the structure. Also referred to as a clear-span or free-span tent.
Butt seam	Seam created when the two pieces being joined are butted together and joined with a strip twice the width of the seam.
Cable cuff	Edge treatment in which the fabric is folded over on itself to form a

	pocket in which a catenary cable can be installed.
Cable fitting	Device attached to the end of a cable to allow a connection to another member. Fittings can be swaged, speltered or compression type.
Canopy	An architectural fabric projection that provides weather protection, identity, and/or decoration and is ground-supported in addition to being supported by the building to which the canopy is attached. The term also can refer to a small tent, a tent without sidewalls or an awning.

Canvas	A coarsely woven natural fabric commonly used in treated form, for tent coverings. It is traditionally 100 percent cotton, but is often used as a generic term for any tent fabric, regardless of its make-up. Also referred to as duck.
Catenary	The curve theoretically formed by a perfectly flexible, uniformly dense, inextensible "cable" suspended from each of two end points. In fabric structures experience, this shape is probably not ever truly developed, but it commonly used to describe the shape developed at the boundary of a uniformly stressed fabric structure attached to a cable which is restrained only at its end points.
Catenary edge	Method of securing the edge of a panel with a cable tensioned between tow fixed points.
Center pole	One or more poles that lie on the longitudinal centerline of the tent and which are used to push the tent fabric up to its highest point, providing a watershed and occupiable space within the tent. Also call an end mast.
Clear span tent	See box beam frame-supported tent
Clevis	Device used with a cable stud end or a threaded rod to form a pinned connection that is somewhat adjustable.
Cold crack	The temperature at which vinyl becomes brittle.
Coating	A material applied to a fabric for waterproofing and protection of the fabric yarns.
Coating adhesion	Strength of the bond between the substrate of a fabric and the coating.
Compensation	The operation of shop fabricating a fabric structure or pieces of the structure smaller in the unstressed condition than the actual installed size, to account for the stretch at pre-stress level.
Connection	Joint, usually mechanical, between two separate components. For example, a welded seam, a cable fitting connected to a weldment, or fabric clamped to perimeter member.
Connection flexibility	A characteristic of a connection which allows for motion between components, such as translation (sliding) or rotation.

Crimp	The extent of deformation normal to the plane of the fabric that the fill and warp yarns undergo as they are woven together
Daylighting	Natural sunlight provided within a space due to the translucency of the fabric.
Dead load	The load on a structure produced by its own weight.
Deadman	A type of uplift anchor, normally buried in the ground (hence its name) which provides anchorage by a combination of its own weight and the weight of the soil captured above it.
Developable	A characteristic of a surface that can be formed using a single flat sheet of material, e.g., a singly curved surface such as a cone or cylinder.

Detension	Relieve the tension or stress in a membrane.
Dressing out	The final tensioning process after the tent has been raised.
Dutch lacing	See becket.
Eave	The lower edge of the tent roof - also referred to as the rim or perimeter.
Eave belt	The reinforcement in the fabric at the tent eave.
Eave guy	A rope, cable or chain attached from the tent eave to the ground anchoring device, normally at the location of the side pole. Also referred to as the side guy.
Egress	The planned avenue to leave the tent safety - also referred to as the exit.
Elongation	The change in lengths of a material sample; normally this is associated with some load or force acting on the sample. In fabric, this elongation does not normally refer to true strain of the fiber elements as in the classical sense; but, rather, normally refers to the 'apparent' strain resulting from a straightening out of the crimped yarns in the fabric matrix.
End mast	See center pole
Equilibrium shape	The configuration that a tensioned fabric surface assumes when boundary conditions, prestress level, and prestress distribution are defined.
Exit	See egress.
Eyelet	Grommet.
Fabric	A woven or laid cloth made of yarns
Fabric clamp	Device for clamping the edge of a fabric panel, usually a bar or channel shape and made of aluminum or steel.
Fiber	The basic thread of the material from which the yarns and fabrics are made.

Fill yarns	See weft yarns.
Flame resistance	A measure of a material's property to resist or retard combustion.
Flange	A rib or rim for strength, for guiding or attaching tent poles together.
Flutter	Excessive, uncontrolled movement, usually caused by the interaction between the structure and wind. This occurs when the fabric lacks sufficient prestress.
Form finding (form generation)	The process of determining the equilibrium shape of a fabric structure.
Frame jack	A portable mechanism for lifting or supporting a tent frame during the raising process.
Free span tent	See box beam frame supported tent
Gore	A special cut, made on the edge of a strip of tent fabric, to produce the desired finished geometry of the surface, sometimes is used to adjust fabric stress distribution.

Greige goods	See base fabric
Guy	A rope, cable or other tie-down element that transfers loads from the tent to the anchoring system, such as stakes or auger embedded into the ground. Also referred to as guy rope or guy line. Types of guys include the eave guy or the top guy.
Guying out	The process of tensioning the tent, while installing, by tightening and adjusting guy ropes.
Helical anchor	See auger.
Hip	The line of the tent roof running from the top of the center pole down to the corner side pole.
Hip band	The reinforcement of the tent fabric along the hip of the tent.
Hip pole	The quarter pole located on the hip of the tent.
Hitch	Any one of a family of adjustable knots, such as a clove hitch, used to fasten a guy rope to a stake.
Hysteresis	The failure of fabric to return to its original geometry after the strain-inducing force has been removed.
IFAI	Industrial Fabrics Association International, a trade association for the industrial and technical fabrics industry, which has a tent rental division dedicated to issues of concern to the tent industry.
Jump rope	A device that fastens to the top of the tent pole to keep it from disconnecting from the tent.
Kip	A unit of force equal to 1,000 pounds.
Laces	See becket.
Lace loops	See becket.
Lace lines	See becket.

Lacing band	The reinforcement in the fabric at the edge of a tent section, which used to lace two sections together. Also referred to as the seams.
Lap seam	Seam created when the two pieces being joined are overlapped by the width of the seam.
Laying	The process of making a fabric by placing the yarns on top of each other without weaving.
Leather eye	See pole hole.
Light reflectivity	A measure of the portion of light striking a fabric surface that rebounds from the surface without being absorbed or transmitted.
Light transmission	A measure of the portion of light striking a fabric surface that passes through the fabric and into the space to provide daylighting.
Liner	A secondary interior fabric membrane, usually non-structural.
Live loads	The force imposed on a structure by its use, composed of the wind load, snow load and earthquake load.
Manila	A general term used to describe rope or cordage made from natural manila hemp fiber.
Marquee	A canopy projecting over an entrance or doorway. Also known as a connecting canopy between two tents.
Modulus of elasticity	The ratio of change in stress to the change in strain. Usually defined as a force per unit width of a membrane material. (this is not identical to the definition of modulus of elasticity as given for traditional structural materials).
Mud shoe	See base plate.
NFPA	National Fire Protection Association, publishers of NFPA 102 and NFPA 701, fire codes affecting rental tents.
Node points	Intersection points of the elements used to define the fabric shape in the structural analysis; these are normally given in terms of a three-dimensional coordinate system.
Non-developable	A characteristic of a surface that cannot be formed using a single flat sheet of material, e.g., a doubly curved surface such as a sphere or saddle-shape.
Occupant load	The total number of people permitted to occupy a structure at any one time.
Patterning	The process of defining two-dimensional pieces of fabric which can be spliced together to form a desired three-dimensional shape.
Pavilion	See tent.
Perimeter	See eave.
Pin	The tip of a tent pole that allows it to slip through an eyelet in the tent fabric and holds the pole top in place.

Pipe frame supported tent	A tent where an assembled framework, made of aluminum or steel pipes, tubes or other extrusions, supports the fabric roof and defines the shape of the structure.
Pitch	The degree of slope in the tent roof, measured by the vertical distance between the tent eave and the peak height of the tent roof.
Poisson's ratio	The ratio of lateral strain to longitudinal strain; may take a wide range of values due to the deformation characteristics of a woven materials. This is not identical to the definition of Poisson's ratio as given for traditional structural materials.
Pole grommet	A reinforced ring fabricated into the tent fabric to accept a pole pin assembly. Also referred to as a leathered-eye, post hole or side pole hole.
Pole supported tent	A tent where a set of individual poles are arranged beneath the fabric roof to support and define the shape of the structure. The fabric roof is tensioned over the poles and attached to ropes and/or cables at designated spots around the fabric's edge. The ropes/cables are anchored to the ground using stakes, augers or weights around the perimeter of the tent. Also referred to as a push-pole tent.
Ponding	The accumulation of water on the tent top.
Prestress	The stress state that exists in a fabric structure when it is not acted upon by service loads; usually induced by the boundary conditions of the fabric membrane.
Purlin	A horizontal member in the roof of a structure, supporting the rafters.
Push pole tent	See pole supported tent.
Quarter band	See storm band
Quarter pole	The poles intermediate between the center poles and the side poles.
Radius of curvature	The inverse of the magnitude of (Gaussian) curvature at a location on a membrane surface. The magnitude is typically considered in two principal directions. The orientation of the principal directions and their magnitude may vary continuously over the surface.
Reinforcement	An additional layer of fabric placed in an area of high stress to protect the main fabric.
Ridge	The line defining the longitudinal axis of the tent roof; this line runs along the center locations at the highest point of the tent roof.
Ridge band	The reinforcement of the tent roof along the ridge.
Rim	See eave.
Roll goods	Raw fabric used in the fabrication of panels for tensioned membrane structures.

Rope	Strands of fiber braided or twisted together, used to tie and secure rental tents. Made from natural fibers or synthetic fillers such as polypropylene, polyethylene and nylon.
Rope edge	Edge treatment in which the edge of the fabric is folded over on itself and a rope or cord is incorporated in the fold to increase the strength of the clamped fabric.
Saddle	The low point in the curve of the fabric roof between center poles of a double curved tensile tent. Also referred to as a swale.
Safety factor	A coefficient used to take into account such uncertainties as variations in material properties, weather, load experiences, fabrication and construction tolerances, etc., a mandatory factor used in architectural design.
Seam	The location at which sections of tent fabric are laced together. See also becket.
Section	A tent roof sub assembly.
Sectionalizing	Method of field joining large fabric panels utilizing clamping hardware.
Side guy	See eave guy.
Sidewall	Sections of fabric attached to the tent at the eave to give the tent walls, enclosing the interior space.
Sidewall rope	Rope attached at the tent eave used to secure the sidewalls to the tent.
Side poles	Poles that support the perimeter of the tent roof.
Sleeve	A tube of fabric, which loosely contains a structural element such as, cable, rod, arch, etc.
Snow load	The weight of snow on the tent top.
Sound reflectivity	A measure of the portion of sound striking a fabric surface that rebounds from the surface without being absorbed or transmitted. Sound reflectivity may be variable across the frequency range.
Sound transmission	A measure of the portion of sound striking a fabric surface that passes through it.
Spelter	Type of cable fitting in which the strands of the cable are opened inside the fitting and molten lead is poured into the fitting to secure the cable.
Stake	A wooden or metal shaft driven into the ground as a tent anchoring device.
Stake driver	A mechanical device used to put stakes into the ground.
Stake puller	A mechanical device used to remove stakes from the ground.
Storm band	The reinforcement of the tent fabric which connects the quarter poles and hip poles continuously around the tent. Also referred to

	as the sweep band, quarter band or wind band.
Stress	Force per unit area.
Swage	Type of cable fitting in which a sleeve fits over the outside of the cable and the sleeve is compressed around the cable to form a tight fit.
Swale	See saddle.
Sweep band	See storm band.
Synclastic	A surface with positive (Gaussian) curvature in both principal direction. A bubble shaped surface.
Tabernacle	See base plate.
Tackle	The arrangement of ropes and associated devices used to lift or pull elements of the tent into position during the installation process. Often used in the phrase 'block and tackle'. See also block.
Temporary structure	Any strucutre, such as a tent, which will be in place for less than 180 consecutive days. Definition may vary according to individual building codes.
Tensile structure	A permanent fabric structure that relies on the tensioning of the fabric roof for its structural integrity and shape. Also referred to as a tension structure or tensioned - membrane structure.

Tensile tent	A temporary fabric structure that shares some characteristics with the pole supported tent, but relies more on the tensioning of the fabric roof for its structural integrity and shape. The use of tensioned fabric to resist applied loads and to shape the fabric membrane means less of a traditional support structure is needed to maintain it.
Tensioned membrane structure	See tensile structure.
Tent	A temporary structure composed of a covering made of a pliable membrane or fabric, supported by such mechanical means as poles, metal frames, beams, columns, arches, ropes, and/or cables. Also referred to as a marquee, canopy or pavilion.
Tent rental division	A division of the IFAI dedicated to issues of concerns to the tent rental industry.
Thimble	Device used in a simple cable loop end to secure the cable and bear against the pin. Thimbles are usually used with shackles.
Top guys	An external rope, cable or chain used to install and secure bail ring tent center poles.
Topping	An additional coating sometimes used on fabric for greater protection against UV degradation or for ease of cleaning purposes.
Translucency	See light transmission.

Turnbuckle	Threaded device used with cables or rods to allow adjustment.
Ultraviolet (UV) degradation	The deterioration of fabric under long-term exposure to sunlight.
Uniaxial	Taken along one direction, usually a principal direction.
Warp yarn	The long straight yarns in the long direction of a piece of fabric.
Webbing	A strong, narrow, closely-woven tape designed for bearing weight and used for straps, harnesses tie-backs, tie-downs, etc. in the tent assembly.
Weather Seal	a form of edge treatment on field joints that provides a weatherproof seal over the joint. Weather seals are not normally under tension and utilize non-structural mechanical or adhesive attachments for connection to a ships hull or decks or another membrane panel.
Weaving	The process of making a fabric from yarns passing alternately over and under each other.
Weft yarn	The shorter yarns of fabric, which usually run at, right angles to the warp yarns. Also called the fill yarns.
Weldment	Connection component, usually steel, for the attachment of cables and/or fabric. It may be free-floating or connected to other membranes.
Wicking	The conveying of liquid by capillary action along and through the yarns of the base fabric.
Wind band	See storm band.
Wind load	The load exerted on a structure due to wind.
Wire rope clip	U-shaped bolt with a special insert specifically designed to clamp a wire rope to itself when forming a loop end for temporary cables.
Wrinkles	Furrows or ridges on the normally smooth surface of a fabric structure, which are indicative of extreme differences between the principal stresses typically resulting form a lower stress perpendicular to the furrow.
Yarn	A number of fibers grouped together to make a thicker strand for weaving. They may be twisted together or parallel to each other.

Appendix B

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Appendix C

Potential Regulatory Impacts

POTENTIAL REGULATORY IMPACT OF THE PROPOSED ENCLOSURE OF DRY DOCKS

The goal of this section is to highlight the applicable regulations concerning people inhabiting the ship during dry dock, people working on the actual repairs and building of ships, and environmental protection.

1) Abrasive Blasting

a) *Particulate Emissions*:
Particulate emissions are derived from the breakdown of the abrasive media. $PM_{10,}$ for example, is defined by the US EPA as total suspended particles less than 10 microns in size, and is a large consideration for the shipbuilding industry. Since concentrations of PM_{10} emissions will increase internally with the enclosure of dry dock activities, new regulatory requirements will apply and therefore this activity is a potential consideration. All air emissions are covered in 40 CFR Parts 50, 51, 52, 57, 60 and 61. Emissions of NAAQS pollutants, such as PM_{10}, are regulated under 40 CFR Part 50. The US EPA has recently revised the particulate matter standards. The primary health-based PM standards will now have an additional annual $PM_{2.5}$ standard. The new limit is 15 $\mu g/m^3$ and a new 24-hour standard set at 65 $\mu g/m^3$. The existing PM_{10} standard is remaining, and the secondary standards will now be identical to the primary standard. (NSRP, 1992)

i) Human Health or Life Safety Effects:
Safety in the workplace is an important consideration in the shipbuilding and repair industry. General hazard communication is an integral component in developing safety standards for an enclosed dry dock and is regulated under EPCRA. This covers all personnel training, written plans and procedures, and emergency contingency plans that the shipyard will have to develop specifically for an enclosed dry dock.

(1) Habitability of Ship:
A ship can be in dry dock from 1 week up to 9 months depending on the services needed. For longer stays, crews often reside on parts of the ship that are not under repair. For international workers, this is of special concern due to their requirement to only remain on international waters and therefore not officially transfer to nearby lodging on land.

(a) Toxic: Toxic considerations are important here as most constituents of PM_{10} can be toxic if not ventilated properly, and there will be an increase in concentration after enclosure.

(b) Flammable/explosive: There will be no additional impact from abrasive blasting after the enclosure.

(2) Shipyard workers in dry dock:

(a) Toxic: Because there will be an increase in the concentration of particulate emissions after enclosure, there is a potential impact on employee health and safety. "*Under OSHA policy, engineering* *controls and work practices are preferred over personal protective equipment to control employee exposures to airborne contaminants."* (J.J.Keller, 1993)

(b) Flammable/explosive: There will be no additional impact after the enclosure.

ii) Environmental effects:

The activities taking place within the enclosed dry dock area are subject to the same environmental regulatory requirements with which an open-air shipyard must already comply. The major environmental compliance issues associated with the enclosure of dry dock activities are in the area of hazardous materials, hazardous waste and solid waste management, air emission control, and water quality.

(1) Water quality:

There may be less adverse environmental effects after the enclosure of dry dock activities as dust particles will not be released to the air, but rather limited to the interior of the enclosure. This will mean less dust floating directly to water, and less floating on to land and indirectly into the water through storm water runoff.

(a) Discharge to Bay or River: Any discharge directly to surface waters from the enclosed dry dock must be permitted under an NPDES permit under Section 402 of the Clean Water Act (CWA). If the quality of the water discharged from the drydock is effected by exposure to increased levels or types of pollutants as a result of the enclosure, it will be important to ensure that these discharges are included in the yard's NPDES permit.

(2) Air quality:

This will differ among shipyards depending on their location, i.e. if they are in an attainment area, the regulations are different than a non-attainment area. All air emissions are covered in 40 CFR Parts 50, 51, 52, 57, 60 and 61.

(a) Discharge to Air: If the shipyard installs a particulate capture system with dry dock enclosure, it will most likely require a permit as a pollution control device. However, if the shipyard is considered a major source and can reduce air emissions after enclosing the dry dock by installing a ventilation system, the shipyard may be able to reduce emissions enough to not be considered a major source, and therefore not require a Title V permit.

The EPA permitting program is governed by 40 CFR Part 71. Section 70.3(a) of Title V regulations require permitting for-:

"Any major source, defined in Section 70.2 of the rules as any stationary source belonging to a single major industrial grouping and that is:

(i) a major source under Section 112 of the Act

(ii) a major source of air pollutants that directly emits or has the potential to emit 100 tons per year or more of any air pollutant (including any major source of fugitive emissions of any such pollutant)" (Government Institutes, Inc. 1997)

(3) Waste from particulate matter can be either hazardous or solid.

(a) Hazardous waste:
After the enclosure, this component may increase as a result of capturing previously uncontrolled emissions. Any waste that is generated must be characterized as either hazardous or non-hazardous. A waste is hazardous if it meets the characteristic or listed hazardous waste criteria in 40 CFR 261.3 (40 CFR 260.10). If personnel in the enclosed dry dock will be working in or around the hazardous waste or satellite accumulation area they will most likely require hazardous waste training (40 CFR 262.34)

(b) Solid waste should remain constant.

b) *HAP emissions* :
These are derived from the breakdown of the existing coating or substrate due to their metal content. Respirable particulates containing toxic metals are of special concern and common to the shipbuilding and repair industry.

i) Human Health or Life Safety Effects

(1) Habitability of Ship

(a) Toxic: As mentioned above, air emissions are a major concern. There will be an additional impact. Please refer to number 1) subsection a) ii) (2) above for regulatory information.

(b) Flammable/explosive: There are no flammable/explosive emissions related to HAP emissions from abrasive blasting.

(2) Shipyard workers in dry dock

(a) Toxic: The concentrations of HAP emissions will be higher after the enclosure even though the contaminants should be contained in a direct line to the outside[1].

(b) Flammable/explosive: There are no flammable/explosive emissions related to HAP emissions from abrasive blasting.

ii) Environmental effects

(1) Water quality

(a) Discharge to Bay or River: There may be a positive effect here as there will be a decrease in the amount of discharge of HAP, after ventilation controls are installed.

(2) Air quality

(a) Discharge to Air: There are few jurisdictions that require air permits for toxic air emissions. If a particulate capture system is installed within the dry dock enclosure, it will most likely require a permit as a

[1] See this section on "Abrasive Blasting" at paragraph 1) a) i) (2) (a) for regulatory requirements.

pollution control device[2].

(3) Waste

(a) Hazardous waste: There is a possibility that there will be more hazardous waste generation from dust particles[3].

(b) Solid waste: There will be no additional impact.

2) Marine Coating Application

a) VOC emissions:

Volatile organic compounds are derived from organic solvents in paints applied in the dry dock.

i) Human Health or Life Safety Effects

(1) Habitability of Ship:

There will be less natural ventilation after enclosing the dry dock likely resulting in an increased concentration of vapors. Please refer to number 1) subsection a) ii) (2) above for regulatory information.

(a) Toxic: VOCs are typically toxic at certain exposure levels, depending on the individual compounds involved. If the concentration is high, PPE may be required to protect persons living aboard the vessel, as well as increased engineering controls.

(b) Flammable/explosive: There will also be an increase in the flammable/explosive potential after enclosure, which will require appropriate safety considerations, and additional ventilation.

(2) Shipyard workers in dry dock:

(a) Toxic: After enclosure the concentration will increase therefore a higher grade of PPE may be required, as well as improved ventilation.

(b) Flammable/explosive: There will also be an increase in the flammable/explosive potential after enclosure, which will require appropriate safety considerations, and additional ventilation.

ii) Environmental effects

(1) Water quality

(a) Discharge to Bay or River: There will be no additional impact.

(2) Air quality

(a) Discharge to Air: VOCs are a regulated pollutant however, enclosing the dry dock will not effect the rate or volume of the emission. Therefore, no additional impact is predicted, unless the shipyard installs VOC destruct equipment within the dry dock enclosure. If installed, this equipment may require a permit as a pollution control device[4].

(3) Waste

(a) Hazardous waste: There are no additional impacts after enclosure

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2 See Section 7.0 "Recommendations"

3 See Section 7.0 "Recommendations"

4 See Section 7.0 "Recommendations"

associated with hazardous waste generation from marine coating application

b) *VOHAP emissions*:
These are derived from organic solvents in paints applied in the dry dock. This is a new group of air contaminants from the EPA, some of which are exempt from being classified as ozone precursors. Title 40 of the CFR, Part 63 highlights the NESHAPs for Source Categories, and specifically defines VOHAP. Volatile organic hazardous air pollutants (VOHAP) are defined as

"any compound listed in or pursuant to section 112 (b) of the CAA that contains carbon, excluding metallic carbides and carbonates. This definition includes VOC listed as HAP and exempt compounds listed as HAP."
(40 CFR, Part 63)
Allowable limits of VOHAP content are listed in Table 2 of Subpart II of Part 63, of Title 40 CFR.

i) Human Health or Life Safety Effects
   (1) Habitability of Ship
      (a) Toxic: The concentration of VOHAPs will increase with the enclosure of dry dock activities, and there will be a need for improved ventilation, or PPE.
      (b) Flammable/explosive: There will also be an increase in the flammable/explosive potential after enclosure, which will require appropriate safety considerations, and additional ventilation.
   (2) Shipyard workers in dry dock
      (a) Toxic: The concentration of VOHAPs will increase and there may be a need for improved PPE or ventilation.
      (b) Flammable/explosive: There will also be an increase in the flammable/explosive potential after enclosure, which will require appropriate safety considerations, and additional ventilation.

ii) Environmental effects
   (1) Water quality
      (a) Discharge to Bay or River: There will be no additional impact.
   (2) Air quality
      (a) Discharge to Air: There will be no additional impact.
   (3) Waste
      (a) Hazardous waste: There will be no additional hazardous waste generated related to VOHAP emissions after enclosure.
      (b) Solid waste: There will be no additional solid waste generated related to VOHAP emissions after the enclosure of dry dock activities[5].

c) *Respirable particulates*:
These are produced from overspray when using paint spray equipment in the dry dock. Solvents evaporate quickly, and the remaining paint particulates may be

[5] See Section 7.0 "Recommendations"

considered respirable by the EPA. Please refer to number 1) subsection a) (2) Shipyard Workers in dry dock, above for regulatory requirements.

i) Human Health or Life Safety Effects
   (1) Habitability of Ship
      (a) Toxic: There will be a need for improved ventilation or PPE with an increase in respirable particulates.
      (b) Flammable/explosive: There will be no additional flammable/explosive issues related to respirable particulates after enclosure.
   (2) Shipyard workers in dry dock
      (a) Toxic: There may be a need for increased PPE levels or improved ventilation.
      (b) Flammable/explosive: There will be no additional flammable/explosive issues related to respirable particulates from marine coating application after enclosure.

ii) Environmental effects
   (1) Water quality
      (a) Discharge to Bay or River: Enclosing the dry dock may result in a decrease in the amount of direct and indirect discharge to nearby waters.
   (2) Air quality
      (a) Discharge to Air: Enclosing the dry dock will reduce particulate emission derived from painting. If a shipyard installs a particulate capture system within the dry dock it may require a permit as a pollution control device[6].
   (3) Waste
      (a) Hazardous waste: There will be no additional generation of hazardous waste from respirable particulates after the enclosure of dry dock activities.
      (b) Solid waste: There will be no additional generation of solid waste from respirable particulates after enclosure.

3) Polyester Layup and Repair Operations

These activities include fiberglassing of prop shafts and other areas of the ship.

a) VOC emissions:

VOC emissions are derived from resin and solvents used in polyester lay up operations in the dry dock.

i) Human Health or Life Safety Effects

   Exposure to styrene is a big concern because of its potential to cause cancer.
   (1) Habitability of Ship
      (a) Toxic: The styrene concentration will increase after the dry dock enclosure, necessitating the installation of ventilation equipment, or

[6] See Section 7.0 "Recommendations"

PPE.

(b) Flammable/explosive: There is a safety concern due to the flammable and explosive nature of the products used for this activity.

(2) Shipyard workers in dry dock

(a) Toxic: The styrene concentration will increase after enclosure, therefore increased levels of PPE will be necessary as well as improved ventilation.

(b) Flammable/explosive: There is a safety concern due to the flammable and explosive nature of the products used for this activity.

ii) Environmental effects

(1) Water quality

(a) Discharge to Bay or River: There will be no additional discharge of VOC emissions to nearby waters after the enclosure of dry dock activities.

(2) Air quality

(a) Discharge to Air: The rate and volume of VOC emissions produced during this activity would not change simply because the dry dock is enclosed. If the shipyard installs VOC destruct equipment, it may require a permit as a pollution control device[7].

(3) Waste

(a) Hazardous waste: There will be no additional impact.

(b) Solid waste: There will be no additional impact.

b) *VOHAP emissions*

VOHAP emissions are produced from the resin and solvents used in polyester lay up operations in the dry dock.

i) Human Health or Life Safety Effects

(1) Habitability of Ship

(a) Toxic: These concentrations will increase after the enclosure, necessitating the installation of ventilation equipment[8].

(b) Flammable/explosive: There will also be an increase in the flammable/explosive potential after enclosure, which will require appropriate safety considerations, and additional ventilation.

(2) Shipyard workers in dry dock

(a) Toxic: Concentrations of VOHAP emissions will increase after the dry dock enclosure, therefore increased levels of PPE and ventilation will be required.

(b) Flammable/explosive: There will also be an increase in the flammable/explosive potential after enclosure, which will require appropriate safety considerations, and additional ventilation.

ii) Environmental effects

[7] See Section 7.0 "Recommendations"

[8] See Section on "Abrasive Blasting" paragraph 1) a) ii) (2) (a).

(1) Water quality
   (a) Discharge to Bay or River: There will be no additional impact to nearby waters from VOHAP emissions after enclosure.
(2) Air quality
   (a) Discharge to Air: The rate and volume of VOHAP emissions produced during this activity would not change after the dry dock is enclosed. If the shipyard installs VOHAP destruct equipment, it may require a permit as a pollution control device[9].
(3) Waste
   (a) Hazardous waste: There will be no additional generation of hazardous waste after enclosure.
   (b) Solid waste: There will be no additional generation of solid waste from VOHAP emissions after the enclosure of dry dock activities.

c) *Particulate emissions*
These are derived from the cutting, grinding, and sanding of fiberglass in the dry dock.
i) Human Health or Life Safety Effects
   (1) Habitability of Ship
      (a) Toxic: There will be an increase in concentration in particulate emissions produced from this activity, therefore there will be a need for better ventilation.
      (b) Flammable/explosive: There are no new or additional flammable/explosive issues related to particulate emissions from polyester layup and repair operations.
   (2) Shipyard workers in dry dock
      (a) Toxic: Since there will be an increase in particulate emissions concentration after enclosure, there will be a need for increased levels of PPE and ventilation.
      (b) Flammable/explosive: There will be no additional impact related to the flammable/explosive nature of this activity after enclosure.
ii) Environmental effects
   (1) Water quality
      (a) Discharge to Bay or River: There may be a positive environmental effect here as there will be a decrease in the amount of discharge of HAP, after the dry dock is enclosed[10].
   (2) Air quality
      (a) Discharge to Air: If the shipyard installs a particulate capture system with dry dock enclosure, it will most likely require a permit as a pollution control device.
   (3) Waste

[9] See Section on "Abrasive Blasting" paragraph 1) a) ii) (2) (a).
[10] See Section on "Abrasive Blasting: paragraph 1)a) ii) (1).

(a) Hazardous waste: The amount of hazardous waste from this activity may increase[11].
(b) Solid waste: There will be no additional solid waste generation related to particulate emissions from polyester layup and repair operations after enclosure.

4) Welding, Brazing, Burning, Cutting

a) Particulate emissions

These are derived from metal fumes produced during welding, brazing, burning and cutting.

i) Human Health or Life Safety Effects
(1) Habitability of Ship : All welding and cutting activities are regulated in Article 49 of the UFC.
(a) Toxic: Concentrations will increase necessitating installation of ventilation equipment.
(b) Flammable/explosive: There will be no additional impact.
(2) Shipyard workers in dry dock
(a) Toxic: There will be an increase in concentration, therefore increased levels of PPE and ventilation will be necessary.
(b) Flammable/explosive: There will be no additional flammable/explosive issues related to particulate emissions from this activity after enclosure.
ii) Environmental effects
(1) Water quality
(a) Discharge to Bay or River: There may be a positive environmental effect here as there will be a decrease in the amount of particulate matter discharge if the dry dock is enclosed[12].
(2) Air quality
(a) Discharge to Air: The discharge of particulates will require a permit if a particulate capture device is installed within the dry dock enclosure[13].
(3) Waste
(a) Hazardous waste: Quantities may increase[14].
(b) Solid waste: There will be no additional solid waste generation from this activity after enclosure.

5) Operation of Internal Combustion Engines

a) NO_x :

These are derived from gasoline and diesel fuel combustion engines operating in the dry dock.

i) Human Health or Life Safety Effects

[11] See Section on "Abrasive Blasting" paragraph 1) a) ii) (3) (a).
[12] See Section on "Abrasive Blasting" paragraph 1) a).
[13] See Section 7.0 "Recommendations"
[14] See Section on "Abrasive Blasting" paragraph 1)a) ii) (3) (a).

(1) Habitability of Ship
  (a) Toxic: Concentrations of NO_x will increase. The permissible exposure limit (PEL) for nitrogen dioxide, for example, is 5 ppm which represents a ceiling limit determined from breathing-zone air samples. Please refer to Appendix A for a few of the allowable levels of regulated indoor air contaminants.
  (b) Flammable/explosive: There will be no flammable/explosive issues related to NO_x emissions from the operation of internal combustion engines.

(2) Shipyard workers in dry dock
  (a) Toxic: There will be a need for increased PPE and ventilation with the increased NO_x levels.
  (b) Flammable/explosive: There will be no flammable/explosive issues related to these emissions from the operation of internal combustion engines after the enclosure of dry dock activities.

ii) Environmental effects
(1) Water quality
  (a) Discharge to Bay or River: There will be no additional impact to nearby waters from NO_x emissions after enclosure.

(2) Air quality
  (a) Discharge to Air: There will be no new or additional requirements for NO_x emissions after the dry dock enclosure.

(3) Waste
  (a) Hazardous waste: There will be no additional generation of hazardous waste from this activity.
  (b) Solid waste: There will be no additional solid waste generation related to NO_x emissions from the operation of internal combustion engines.

b) SO_x :

This is derived from gasoline and diesel fuel combustion engines operating in the dry dock. Emissions of NAAQS pollutants, such as sulfur dioxide are regulated under 40 CFR Part 50. The PEL for sulfur dioxide, for example, is 5 ppm. Please refer to Appendix A for a few of the allowable levels of regulated indoor air contaminants.

i) Human Health or Life Safety Effects
(1) Habitability of Ship
  (a) Toxic: There will be an increase in SO_x concentrations after enclosure necessitating improved ventilation equipment.
  (b) Flammable/explosive: There are no flammable/explosive issues related to SO_x emissions from the operation of internal combustion engines.

(2) Shipyard workers in dry dock
  (a) Toxic: Additional PPE and/or ventilation equipment will be necessary after enclosure to protect employees.
  (b) Flammable/explosive: There are no flammable/explosive issues related

to SO_x emissions from the operation of internal combustion engines.

ii) Environmental effects
  (1) Water quality
    (a) Discharge to Bay or River: There will be no new or additional discharges to nearby waters after the enclosure of dry dock activities.
  (2) Air quality
    (a) Discharge to Air: There will be no new or additional requirements for SO_x emissions after the dry dock enclosure.
  (3) Waste
    (a) Hazardous waste: There will be no additional generation of hazardous waste from this activity after enclosure.
    (b) Solid waste: There will be no additional solid waste generated if the dry dock is enclosed.

c) CO_2:

Carbon dioxide is derived from gasoline and diesel fuel combustion engines operating in the dry dock.

i) Human Health or Life Safety Effects
  (1) Habitability of Ship
    (a) Toxic: Concentrations of CO_2 will increase after enclosure. Again, additional ventilation should be adequate in abating the extra levels. The PEL for CO_2 is 5000ppm. Please refer to Appendix A for a few of the allowable levels of regulated indoor air contaminants.
    (b) Flammable/explosive: There will be no additional flammable/explosive issues related to carbon dioxide emissions from the operation of internal combustion engines.
  (2) Shipyard workers in dry dock
    (a) Toxic: After enclosure, with increased concentrations, additional PPE and ventilation will be required.
    (b) Flammable/explosive: There will be no additional flammable/explosive issues related to carbon dioxide emissions from the operation of internal combustion engines.

ii) Environmental effects
  (1) Water quality
    (a) Discharge to Bay or River: There will be no new or additional discharges to nearby waters from this activity.
  (2) Air quality
    (a) Discharge to Air: Since there will be an increase in concentration of carbon dioxide in the air after enclosure, it will be worth looking into the use of improved ventilation equipment or processes (refering to passive ventilation i.e. opening panels or vents)for abatement.
  (3) Waste
    (a) Hazardous waste: There will be no additional generation of hazardous waste from this activity.

(b) Solid waste: There will be no extra solid waste generation related to CO_2 emissions from the operation of internal combustion engines after enclosure.

d) *CO*:
Carbon monoxide is derived from gasoline and diesel fuel combustion engines operating in the dry dock.

i) Human Health or Life Safety Effects
(1) Habitability of Ship: When any part of the ship is enclosed, carbon monoxide from the operation of internal combustion engines within the enclosure is a concern.
(a) Toxic: Concentrations of CO will increase with the enclosure of dry dock activities and therefore necessitate improved levels ventilation. The PEL for CO is 50ppm. Please refer to Appendix A for a few of the allowable levels of regulated indoor air contaminants.
(b) Flammable/explosive: There will be no additional flammable/explosive issues related to CO emissions from the operation of internal combustion engines after enclosure.
(2) Shipyard workers in dry dock
(a) Toxic: There will need to be improved levels of PPE and ventilation with the increased concentrations of CO.
(b) Flammable/explosive: There will be no additional flammable/explosive issues related to CO emissions from the operation of internal combustion engines after enclosure.

ii) Environmental effects
(1) Water quality
(a) Discharge to Bay or River: There will be no new or additional discharges of CO to nearby waters after enclosing dry dock activities.
(2) Air quality
(a) Discharge to Air: CO is a regulated pollutant and therefore will be subject to permitting requirements under Title V if threshold levels are exceeded. Enclosing the dry dock will not effect the rate or volume of CO emissions[15].
(3) Waste
(a) Hazardous waste: There will be no new or additional generation of hazardous waste from CO emissions from the operation of internal combustion engines after dry dock enclosure.
(b) Solid waste: There will be no additional solid waste generation related to this activity after enclosure.

e) *Particulate emissions*:
Particulate emissions are derived from the combustion of diesel fuel.

[15] See Section "Abrasive Blasting" paragraph 1) a) ii) (2) (a).

i) Human Health or Life Safety Effects
   (1) Habitability of Ship
      (a) Toxic: Concentrations of particulate emissions from the internal combustion engines will increase after the enclosure. Improved ventilation will be necessary.
      (b) Flammable/explosive: There will be no additional impact.
   (2) Shipyard workers in dry dock
      (a) Toxic: After the enclosure of dry dock activities, employees will require improved levels of PPE and/or ventilation due to increased concentrations.
      (b) Flammable/explosive: There will be no additional flammable/explosive issues related to particulate emissions from the combustion of internal engines after enclosure.

ii) Environmental effects
   (1) Water quality
      (a) Discharge to Bay or River: There will be no new or additional discharges of CO to nearby waters after enclosure.
   (2) Air quality
      (a) Discharge to Air: Particulate matter is considered a major source of air contaminants and therefore will be subject to permitting requirements under Title V[16].
   (3) Waste
      (a) Hazardous waste: There will be no additional generation of hazardous waste after the dry dock enclosure.
      (b) Solid waste: There will be no new or additional solid waste generated related to particulate emissions from the operation of internal combustion engines after enclosure.

[16] See Section "Abrasive Blasting" paragraph 1) a) ii) (2) (a).

LIST OF ACRONYMS

CAA	Clean Air Act
CERCLA	Comprehensive Environmental Response, Compensation and Liability Act
CFR	Code of Federal Regulations
CO	Carbon monoxide
CO_2	Carbon dioxide
CWA	Clean Water Act
DOT	Department of Transportation
EPA	Environmental Protection Agency
EPCRA	Emergency Planning and Community Right to Know
ESA	Endangered Species Act
FIFRA	Federal Insecticide, Fungicide, and Rodenticide Act
HAP	Hazardous Air Pollutant
NAAQS	National Ambient Air Quality Standard
NESHAPS	National Emission Standard for Hazardous Air Pollutants
NEPA	National Environmental Policy Act
NOx	Nitrogen oxides
NPDES	National Pollutant Discharge and Elimination Strategy
OPA	Oil Protection Act
OSHA	Occupational Safety and Health Act
P2	Pollution Prevention
PEL	Permissible Exposure Limit
$PM_{2.5}$	Total suspended particles less than 2.5 microns in size
PM_{10}	Total suspended particles less than 10 microns in size
PPE	Personal protective equipment
PT	Total particulate matter
RCRA	Resource Conservation and Recovery Act
SARA	Superfund Amendment and Reauthorization Act
SDWA	Safe Drinking Water Act
SOx	Sulfur oxides
TSCA	Toxic Substances Control Act
TWA	Time Weighted Average
UFC	Uniform Fire Code
VOHAP	Volatile Organic Hazardous Air Pollutant

REFERENCES

Government Institutes, Inc., Environmental Law Handbook Fourteenth Edition, 1997.

J.J. Keller, *OSHA Compliance Manual: Application of Key OSHA Topics*, 1993.

NSRP, *Environmental Compliance Inspection Checklist for Shipbuilding Facilities*, 1992, NSRP document number 0345.

NSRP, *Introduction to Production Processes and Facilities in the Steel Shipbuilding and Repair Industry*, February 1993, NSRP document number 0382.

US EPA, Office of Compliance Sector Notebook Project: *Profile of the Shipbuilding and Repair Industry*, 1997.

International Fire Code Institute, *Uniform Fire Code Volume 1*, 1994.

Websites:
NSRP
US EPA

Appendix A

Regulated levels for several indoor air contaminants produced during shipbuilding and repair activities are listed in the table below. It is important to note here that the EPA lists these levels as allowable in the workplace, but expects the employer to figure out how to stay below the levels. The PELs are 8-hour TWAs unless otherwise noted: a letter (a) designates a ceiling limit determined from breathing-zone air samples.

Table 2 Regulated Indoor Air Contaminant Levels

Air contaminant	ppm[1]	Mg/m^3 [2]
Acetic acid	10	25
Acetone	1000	2400
Aluminum – dust	-[3]	15
-respirable fraction	-	5
Benzene	10, 25(a)	-
2-Butanone (methyl ethyl ketone)	200	590
Carbon dioxide	5000	9000
Carbon monoxide	50	55
Cyanides (as CN)	-	5
Hexone (methyl isobutyl ketone)	100	410
n-Butyl alcohol	100	300
Nitrogen dioxide	(a)5	(a)9
Sulfur dioxide	5	13
Sulfuric acid	-	1
Toluene	200, 300(a)	-
Xylene (o-, m-, and p-isomers)	100	435

1 The ppm are parts of vapor or gas per million parts of contaminated air by volume at 25°C and 760 torr.

2 The mg/m^3 are milligrams of substance per cubic meter of air. When entry is in this column only, the value is exact; when listed with a ppm entry, it is approximate

3 hyphen indicates no standard provided in applicable concentrations units.

Appendix B **Potential Aspects and Impacts Associated with Enclosing Dry Dock Operations**

Aspects	Environmental Impacts	Health and Safety Impacts	Legal Requirements
Surface preparation	Hazardous waste Hazardous materials handling, use and storage Solid waste VOC emissions	Chemical absorption Small-scale spills and exposures	29, 33, 40 CFR CAA, P2 Act, TSCA, RCRA, SARA, EPCRA, OSHA
Metal Plating and Surface Finishing	Air contaminants Wastewater discharges Hazardous waste Hazardous materials handling, use and storage	Inhalable dust, chemical absorption Spills and exposures Emergencies – fire, explosions	29, 33, 40 CFR CAA, CWA, P2 Act, SDWA, TSCA, RCRA, SARA, EPCRA, OTA, ESA, OSHA
Painting	Air contaminants Surface water discharge Hazardous waste Hazardous materials handling, use and storage Solid waste	Inhalable dust, chemical absorption Spills and exposures	29, 33, 40 CFR CAA, CWA, OPA'90, P2 Act, SDWA, TSCA, RCRA, CERCLA, SARA, EPCRA, OTA, ESA, NEPA, OSHA
Fiberglass Reinforced Construction	Airborne fibers Wastewater Solid waste Hazardous materials handling, use and storage	Inhalable dust, dermal absorption Spills and exposures	29, 33, 40 CFR CAA, CWA, P2 Act, SARA, EPCRA, OSHA
Machining and Metal Working	Air contaminants Hazardous materials handling, use and storage Metal and oily waste	Inhalable dust Spills and exposures Emergencies – fire, explosions	29, 33, 40 CFR OPA'90, RCRA, SARA, EPCRA, OSHA

Appendix D

Catalogue

Table of Contents

Catalogue of Tensile Systems & Components

Forward:

This catalogue is a collection of manufacturers, designers, and suppliers of fabric tensile systems and components. Some of the companies offer unique and hard to find products that may be useful in building enclosures in shipyards. Many of the businesses in this catalogue perform or supply multiple services or products. Rather than duplicate listings, companies are placed in their primary function. This is not a comprehensive listing of all businesses involved in the various categories. The Industrial Fabric Association International (IFAI) prints a Designers Guide for industrial fabrics. This is comprehensive source of fabric and hardware suppliers. The Guide has a listing of available fabrics and their properties. The IFIA is listed in this catalogue.

Academic Institutions

New Jersey Institute of Technology

Website contains lists of engineering firms, firms with websites, material fabricators and there useful information on tensile structures
Website: http://www.njit.edu

Associations

Industrial Fabric Association International (IFAI)
1801 County road B W, Roseville, MN 55113, Telephone (800) 225-4324
Website: www/ifai.com
Comprehensive source of tensile building resources, design, fabric, structure

Containment Systems

Rapid Deployable Systems LLC
2061 Avenue B. North Upper, North Charleston SC 29405
Phone (843) 740-1831
Website: www.rapid-ds.com

Trax Enclosure System

Eagle Industries P.O. Box 10652, New Orleans, LA 70181, Ph. (504) 733-3510
Website: www.trax.com

Walton Technology, Inc. Sail System

1810 Woodville Drive Suite 200, Sevoy, Il. (800) 225-7704

Designers & Construction Firms

Air Structures American Technologies Inc.

211 South Ridge Street, Rye Brook, New York 10573
(914) 937-4500 / 1-800-AIR-BLDG, FAX (914) 937-6331
E-Mail: ASATI Website: http://www.airbldg.com

Birdair, Inc.

622-65 Lawrence Bell Drive, Amherst, New York14221 -USA
TEL: (716)-633-9500 or 8002246, FAX: (716) 633-9850
Website: www.birdair.com/

CMR Environmental Energy Research & Development

21 Armstrong Avenue, Unit #2, Georgetown, Ontario, Canada, L7G 4S1,
Telephone (907) 873-4140
Compressible Structures

Curtain Total Containment

Mr. Robert Davis, , 200 Holland Drive, Camden, NC 27921, Phone (252) 333-1458
Developing a cable supported curtain system, wing wall to ship

FTL/Happold

Architects & Engineers, 157 Chambers Street, NY NY 10007, 212.732.4691 tel.
212.385.1025 fax
Website: www.ftl-happold.com

Geiger Engineers, P.C. Bellingham Office

1215 Cornwall Avenue, Bellingham WA 98225
phone: 360-734-7194, fax: 360-734-7399
Website: www.geigerengineers.com

Harry B. Daugherty P.E.

Consulting Engineers, Box 2854, Whitehouse, Ohio 43571 Phone (419) 877-0243
Fax:(419) 877-9488, E-mail: hbdaugh@bright.net
Website: www.hbdaugherty.com

Permafab Pty Ltd

Level 3, The Eastwood Centre, 160 Rowe Street, EASTWOOD NSW 2122
Tel : (61-2) 9858 3678 **Fax :** (61-2) 9858 3890
Website: www.ozemail.com.au/~permafab

Skyspan International

Skyspan (UK) Limited,
Enterprise House, Cherry Orchard Lane, Salisbury, Wiltshire SP2 7LD, UK
Tel: +44 (0)1722 331599 Fax: +44 (0)1722 415922
Website: www.skyspan.com

Span Systems

104 Epping Road, P.0. Box 1075, Exeter NH 03833
Phone 800 558-3003, Fax 503 772-7918
Website: www.spansystemsinc.com

Special Structures Lab

Unit 1A Sheffield Technology Park, 60 Shirland Lane, Sheffield, S9 3SP UK
tel: +44 (0) 114 22 11 650 fax: +44 (0) 114 22 11 651
e-mail: ssl@specialstructures.com, website: www.specialstructures.com

Taiyo Kogyo Corporation

Website: http://www.taiyokogyo.co.jp

Technet gmbh

Website: www.technet-gmbh.com
Technet's web page contains links to building, suppliers, associations and academic institutions. Technet is a design firm.

Tentnology

15427 66th Avenue, Surrey, British Columbia V3S 2A1, Phone 800 663-8858
Website: www.tentnology.com

Fabric Manufacturers

Fabrimax

1095 Ridgeside Dr., Monterey Park, CA 91754,
Tel: (626) 570-8884; Fax: (626) 576-0137
Email: info@fabrimax.com, Website: http://www.fabrimax.com/
Silicone Coated Fiberglass

Reeves Brothers

Engineered Coated Fabrics 1-800-635-9350 Fax 1-864-595-2211
Website: hwww.reevesbrothers.com
Silicone Coated Fiberglass

Kosa

Global Headquarters, 15710 JFK Boulevard, Houston, TX 77032
Tel: 281-986-1400
Website: www.kosa.com
Coated & laminated polyester, fire resistant

Monarflex, Inc

1412 N. Sam Houston Pkwy. E. suite 100, Houson TX 77032
281-442-1440 fax 281-442-4429
sheeting with rubber grommets installed

Seaman Corporation

1000 Venture Blvd. Wooster, Ohio 44691
800.927.8578 FAX: 800.649.2737
Website: http://www.seamancorp.com/

Taconic Industrial Fabrics Division

Mr. Steve Denbow, 2475 Norhtwinds Parkway, Suite 200, telephone (770) 640-7829.
Email: steved@4taconic.com. Website: www.4taconic.com
PTFE coated fiberglass

Tex-Net, Inc.

Box 17 Roebling, NJ, 08554
Phone 800-541-1123
Webpage: www.powercage.com
Windscreen, netting

TMI, Inc.

5350 Campbells Run Road, Pittsburgh, PA 15205-9738,
Phone: 800.888.9750, 412.787.9750, Fax: 412.787.3665
E-mail: customer-service@tmi-pvc.com Website: www.tmi-pvc
PVC sheeting and strip doors

Fabric Doors

Megadoor, Inc.

P.O. Box 2957, Peachtree City, GA 30269 Telephone: (770) 631-2600,
Website: http: www.megadoor.com

Para-Port Doors

1801 Sandusky St., Fostoria, OH 44830 (419) 435-7676

Manufactured Modular Fabric Structures

Canvas Specialties

7344 East Bandini Boulevard, Los Angeles, CA 90040, USA
U.S. Toll-free: 1-800-423-4082, Phone: (323)) 723-8311 Fax: (323) 724-3848
Website: www.can-spec.com

Clamshell Buildings

1990 Knoll Drive, Ventura, CA 93003
Phone: (800) 360-8853 or (805) 650-1700, Fax: (805) 650-1733
Website: www.clamshell.com

Hansen Weatherport Corp.

Phone; (970) 323-5932
Website: www.weatherport.com

National Tent, Inc.

Randy McCauly, National Tent, Inc. (NTI), 32052 S. Ona Way, Molalla, OR 97038,
Phone: (503) 829-5547
Assisted ASD with prototype tensile structure for ships

Polysteel Corporation

P.O. Box 1488, Quincy FL 32353
501-438-2850

Satellite Shelters, Rubb Building Systems

Mr. Sid Morrell., P.O. Box 1930, Port Townsend, WA 98366.
Telephone (360) 379-9718
Website: www.rubb.com

Sprung Instant Structures

Toll Free: 1-800-528-9899
Direct Dial: 801-280-1555
Website: www.sprung.com

Universal Fabric Structures

2200 Kumry Road, Quackertown PA, 18951, Phone 800 634-8368
Website: www.ufsinc.com

Scaffold System & Roof Trusses

HAKI UK LTD.

Mr. Irving Bullock, Tame Valley Industrial Estate, Tamworth Staffs, B77 5BY.
Phone 01560321879.
Website:www.haki.co.uk

Structural Components

Water Structures Unlimited,

Phone: 800-693-5055, Fax: 707-768-2116, E-mail: wsu@humboldt1.com
Website: www.waterstructures.com
Manufacturer of water filled tubes for anchors and weather seals

Doughty Engineering

USA Exclusive Distributor, Hollaender Mfg. Co., P.O.Box 156399, Cincinnati OH 45215-6399 USA, toll free:800-772-8800, Fax: 513-772-8806
Website: www.doughty-engineering.co.uk
Manufactures aluminum scaffold clamps

Contact Systems.

KarlstraBe 70, D-89547, Gerstetten, Germany. Tel: 073 23/96 20-0.
Web Site http://www.contac-systems.com/homee.html
Manufactures aluminum trusses, scaffold clamps and portable stages

Edge International

30262 Crown Valley Parkway, Suite 273, Laguna Niguel, CA 92677
Tel: (800) 628-EDGE (949) 495-5666 Fax: (949) 495-4161
Website: www.edgeintl.com
Scaffold and beam clamps

Extren – Fiberglass Structural Shapes

P. O. Box 580 / Bristol, Virginia 24203-0580 USA
Phone: (540) 645-8000 / Fax: (540) 645-8132
Website: www.strongwell.com

Harken, Inc.

1251 East Wisconsin Ave., Pewaukee, Wisconsin 53072
Tel: (262) 691-3320 Fax: (262) 691-3008
Website: www.harken.com
Masts, rigging and fittings – sailing vessels

Kee Klamp

Kee Industrial Products, Inc., 100 Stradtman Street, Buffalo, NY 14206
Phone: (716) 896-4949, Toll-Free: (800) 851-5181, Fax: (716) 896-5696
Email: info@keeklamp.com, Website: www.keeklamp.com
Fittings for assembling tubular frames

Littlestown Hardware & Foundry Co.

P.O. Box 69, Littlestown, Pennsylvania 17340
717-259-4141, fax 717-359-5010
clamps, fittings for awnings

Syntechnics, Inc FRP Division

Mr. David Schoate, 700 Terrace Lane, Paducah, KY 42003,
Phone: (502) 898-7303

Tension Technology International, Inc

TTI House, 28 Ribblesdale Place, Preston, Lancs., PR1 3NA UK
Phone: (0) 1772-556000 Fax: (0) 1772-556622
e-mail: TTI.Ltd@tensiontech.com
Website: www.tensiontech.com

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P.O. Box 550, Midland, TX 79702. Mr. Keith Bohn, Asst. U.S. Sales Manager,
Phone (915) 694-7070 ext. 25. Fax (915) 689-3805. E-mail: kbohn@tomcatusa.com.
Website: www.tomcatusa.com
Portable stage structures and fittings

Transerve Engineering HK LTD

Unit B11,4/R Tonic Industrial Centre, 19 Lam Hing Streeet, Kowloon Bay, Hong Kong, Tel; 852-751-8891, fax: 852-795-1267
Space frame structures & trusses

Triodetic Space Frames Inc.

4465 East Genesee Street #306, Syracuse, New York, USA 13214
Phone: (800) 565-2743, Fax: (315) 453-7817
Website: www.triodetic.com

Rubans Gallant

Website: www.rubans-gallant.com/us
Manufactures technical tapes and webbing, is developing a self tensioning system

Tubing, Steel Galvanized & Coated

Allied Tube & Conduit

16100 South Lathrop Avenue, Harvey, IL 60426
(800) 882-5543; Fax: (708) 339-2399
Website: www.alliedtube.com/

Wheatland Tubing Company

900 Haddon Avenue, P.O. Box 600, Collingswood, NJ 08108-0600 U.S.A.
Phone: 1-800-257-8182
Website: www.wheatland.com

RhinoTube LLC

17 Wood Street, West Haven C& 06516
1-800-251-0858 • 203 479-8599 • fax 203 937-9313 • info@rhinotube.com
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Phone: 401-762-5500, Fax: 401-762-5514
Website: www.acw1.com

Cargo Control Systems
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Phone: 9990-614-7820, Fax 770-614-7821
Ratchets and strapping

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206-623-0466 fax 206-682-6205
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Euro Products, Inc.
1557 N.W. Ballard Way Seattle WA 98107
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Röhre 50 - 59846 Sundern Germany
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400 Middle Street, Brostol, CT 06010
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900-585-7134 Buckles, snap locks and rings

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Sea Catch

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Website: http://ourworld.compuserve.com/homepages/seacatch/
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Website: www.ykkamerica.com

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